DEVELOPMENT OF A STRAIN CONTROLLED MONOCELL PRESSUREMETER

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CONTENTS

NOMENCLATURES

a	:	Radius of cavity.
a_o	:	Initial radius of cavity.
C_u	:	Undrained shear strength.
E	:	Elastic modulus.
G	:	Shear modulus.
K_o	:	Coefficient of earth pressure at rest.
MPM	:	Me'nard Pressuremeter test.
N	:	Standard penetration number.
N_c	:	Bearing capacity factor.
N_p	:	Pressuremeter constant.
PBP	:	Prebored pressuremeter test.
p_F	:	Yield pressure.
p_L	:	Limit pressure.
p_o	:	Total insitu horizontal earth pressure.
q_c	:	Cone resistance.
SCPT	:	Static cone penetration test.
SPT	:	Standard penetration test.
V	:	Volume of cavity.
V_m	:	Mean volume of cavity over elastic range.
V_o	:	Initial voluem of cavity.
ε_c	:	Cavity strain.
ε_r	:	Radial strain.
ε_θ	:	Circumferential strain.
η	:	Radial displacement at radius r.
η_c	:	Change in radius of cavity.
ν	:	Poisson's ratio.

σ_o : Over burden pressure.

σ_r : Radial stress.

σ_θ : Circumferential stress.

ϕ : Angle of internal friction of soil.

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ABSTRACT

It has been realized that equipment available in the Indian market for pressuremeter testing is complicated and does not reflect the latest trends in the design. As such, a much simplified pressuremeter called Cavity Expansometer (CAVITEX) has been design and built. It has been tested under actual field conditions and results are compared with Standard penetration, Static cone penetration and conventional pressuremeter tests. Performance of the equipment has been found to be entirely satisfactory.

CHAPTER I

INTRODUCTION

1.1 GENERAL

Testing of soil for assessment of its index and strength properties for the purpose of design is often a very complex process. The problem is aggravated by the fact that soils besides having wide variation in basic structure, are extremely heterogeneous. It has been long ago recognized that laboratory methods of soil testing are inadequate to give the complete solution of the problem at hand because of the following reasons:

(1) Disturbances of soil structure during sampling.

(2) Stress release and change in pore water pressure during subsequent storage.

(3) Impossibility of obtaining representative samples in certain type of soils.

Several in-situ tests have been developed over the years to circumvent the above shortcomings of laboratory tests. Some of the commonly used tests are:

(1) Standard Peneteration Test.

(2) Static and Dynamic Cone Penetration Tests.

(3) Vane Shear Test.

(4) Plate Load Test.

(5) Pressuremeter Test.

In all kinds of penetration tests a metallic body of standard geometry is forced into the ground by impact of a falling weight or under a static driving force. Resistance offered by soil is measured and is correlated empirically to various soil properties. The tests measure ultimate or failure parameters only and give no

idea about stress-strain relationship of soil before it fails. Vane shear test generally leads to an overestimation of strength since it causes failure on predetermined plane which is not likely to correspond to the weakest plane. Moreover, its application is restricted to soft to medium clays only. Plate load test is considered superior to other in-situ methods, but it is very costly and can be performed only at shallow depths in limited number.

1.2 IMPORTANCE OF PRESSUREMETER TESTING

The above mentioned factors have lead to the development of pressuremeter which is the only equipment available to carry out large number of in-situ, truely static load tests at depth. Some of the advantages offered by pressuremeter are listed below.

(1) It is a truely static test which can be performed in either undrained or fully drained condition.

(2) It is the only in-situ test which yields a stress-strain relationship in all types of soil and soft rocks in a well defined simple state of stress.

(3) It can be performed at any desired depth, above or below water table.

(4) Though it is possible to correlate empirically the results of pressuremeter test with various soil parameters, there exists various well established theories for the interpretation of the test results.

(5) The test is capable of giving more representative values of properties averaged over a large volume of soil.

1.3 HISTORY OF DEVELOPMENT

The idea of expanding bore hole wall with the help of a balloon like device in order to measure the stress-strain responce

of soil owes its origin to Kögler a German engineer who wrote about such a device and came up with a practical design in 1933. Interestingly, he used a 100 mm diameter, 1250 mm long single compartment cylindrical probe which he inflated by gas pressure. However, Kögler had difficulties in computing the actual volume changes of the probe and interpreting the results. Though he worked for about seven years with the device, his work went more or less unnoticed.

It was in 1955 that a young French engineer Louis Me'nard revived the idea and introduced a major change in the design of the probe. Instead of one long cylinder, the probe consists of three seperate cells capable of being inflated to approximately twice their original volume by carbon dioxide gas pressure applied from a cylinder at the surface as shown in figure 1.1. The probe is lowered into a prebored hole and pressure is applied in steps as shown in Figure 1.2 a .

Each step is kept constant for about 1 to 2 minutes and volume change measurements corresponding to 15, 30 and 60 seconds are taken simply by measuring the amount of water injected into the central cell called 'measuring cell'. No volume change measurements are made in outer cells which are expanded to the same pressure. Outer cells also called 'guard cells' are said to eliminate the end effects introduced by the finite length of the probe ensuring plane strain condition around the measuring cell. Results after applying certain corrections are plotted as a pressure versus volume curve as shown in Figure 1.2 b. The curve corresponding to the difference between 30 seconds and 60 second reading is called 'creep' curve. A typical curve obtained from

pressuremeter can be divided into three parts. Referring to Figure 1.2 b, the portion up to the point A represents the applied pressure overcoming the disturbances and local stress relief due to formation of borehole. During this phase of test 'creep' is relatively high. The next portion (AB) represents the elastic response of material. During this phase recorded creep is minimum. As pressure is increased further, yielding takes place and 'creep' increases. This represents the plastic behaviour of material. A condition of 'Limit pressure' is reached at which the cavity continues to expand 'indefinitely'. Thus parameters which characterise a pressuremeter curve are :

(1) p_o the pressure corresponding to the start of linear portion.

(2) p_F the pressure corresponding to the end of linear portion.

(3) p_L the limit pressure conventionally defined as pressure corresponding to double the original size of cavity.

(4) Mass modulus E obtained from slope of linear portion (Section 3.5.2).

The instruments currently in use are type GC with 2500 KPa capacity and type GB with 10000 KPa capacity (Fig 1.1). Each instrument can be supplied with a series of probes which correspond to the most usual borehole diameters.

DCDMA code	Diameter of Probe (mm)	Borehole Diameter Minimum	Maximum	Probe Volume
EX	32	34	38	535
AX	44	46	52	535
BX	58	60	66	535
NX	74	76	80	790

The test procedure and interpretation methods are standardized for Me'nard pressuremeter (MPM) and design methods based on the emperical evidences are available for the design of foundations (Baguelin et al. 1978).

As the pressuremeter technique gained acceptance outside France several equipments, often differing from MPM with respect to probe dimensions and configuration, mode of operation and measurement system were built in Japan, Canada and Australia. OYO Corporation of Japan manufactured the moderate capacity (50000 KPa) pressuremeter called 'Lateral Load Tester (LLT). It consists of a single cell (Kögler type) probe of 80 mm diameter and 900 mm total length. The cell of load unit which is 600 mm long, can be expanded with carbon dioxide gas. A high capacity device (20000 KPa) called 'Elastmeter' manufactured by the same company is having a monocell probe which contains displacement detecting mechanism to measure the diameter of the bore hole at any stage of test thus eliminating the requirement of volume measurement. This type of mechanism is also used in COFFEY PMX-20 pressuremeter (Ervin et al. 1980) developed by M/S Coffey partners of Australia 1978. The equipment is designed for NXsized bore hole. The expanding membrane is 400 mm long. Sensors are designed to measure displacement at four positions 90^{o} apart on the centre line. All equipments described above are stress controlled. Strain controlled equipment was first built by Bission and Marigner in France (Baguelin et al. 1978). Recently M/S Rocktest of Canada has marketed strain controlled equipments (Capelle, 1983).

Results of prebored pressuremeter are considerably affected by drilling disturbances and stress release in the soil surrounding the borehole. To avoid these problems researchers in England and France developed 'selfboring technique' in early 70's. This allows the probe to be inserted into the ground in a borehole made by the probe itself, with little or no disturbances. Selfboring pressuremeters represent the state of the art in the field of in-situ testing of soil. As present study is concerned with the developement of a prebored pressuremeter, these devices are not described here.

1.4 STATUS IN INDIA

Despite the potential of pressuremeter test to cover the requirements of wide range of Indian soils, the test is extremely underused. Following reasons can be given:

(1) The equipment and test procedure in their original form are too sophisticated to be widely used under the existing field practice in India (Figure 1.3).

(2) Till 1979 the equipment was not manufactured in India.

(3) The available equipments are all very costly.

S.Venkatesan of Central Building Research Institute of Roorkee in colaboration with M/s Associated Instrument Manufacturers Ltd. of New Delhi undertook the development of what is now known as SUBSOIL DEFORMETER (Venkatesan, 1980). Unfortunately the design of probe and surface unit is marginally different from that of GC type (Figure 1.4 and Plate 1); it was natural that the equipment never came into a wide spread use.

1.5 MOTIVATION AND SCOPE

From the experience with SUBSOIL DEFORMETER it is realized that a much simplified equipment which retains all inherent advantages of pressuremeter technique as enunciated earlier is needed for Indian engineers. A mannually operated, strain controlled, monocell pressuremeter should fulfil this requirement. One such pressuremeter has been designed, built and tested keeping in view the simplisity of design, ease of operation and robustness of construction, requirements typical of the Indian condition. Such an equipment could be an invaluable addition to the SPT and other field tests used at present in India.

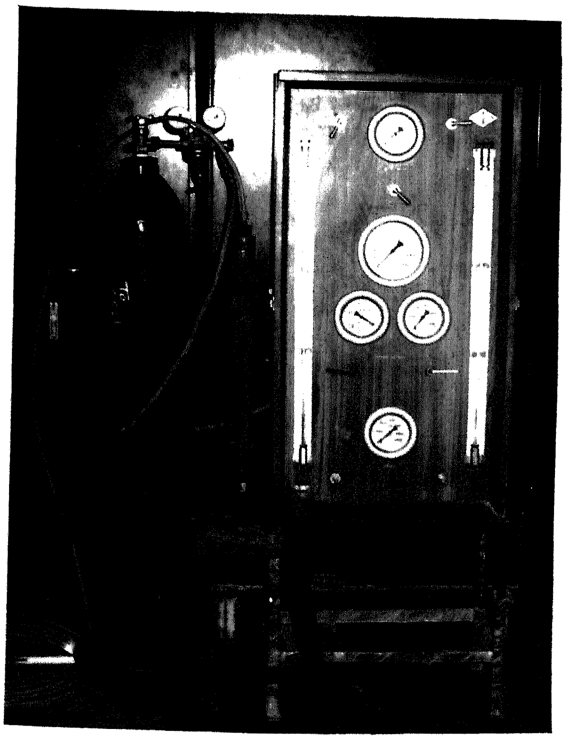
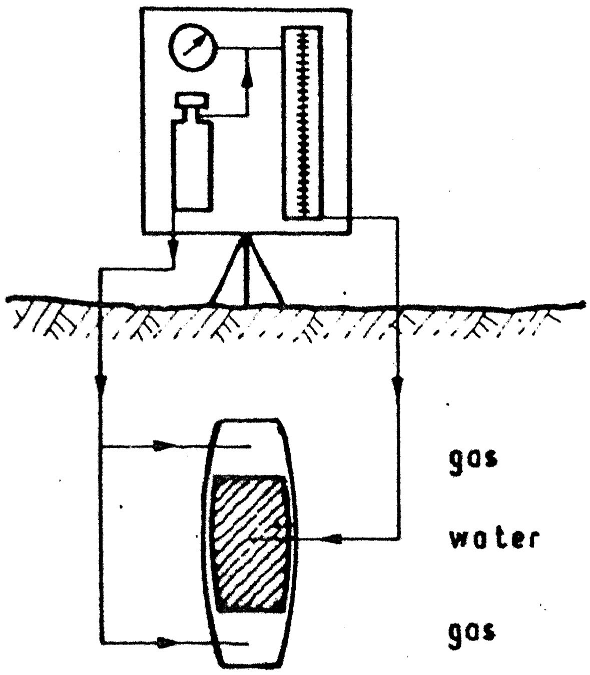
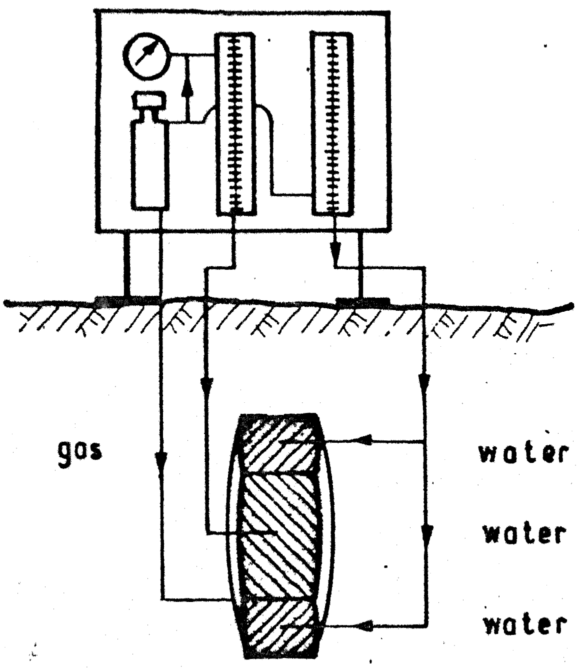


Plate 1



(a) GC TYPE



(b) GB TYPE

FIG. 1.1 ME'NARD PRESSUREMETERS (After Baguelin,1978

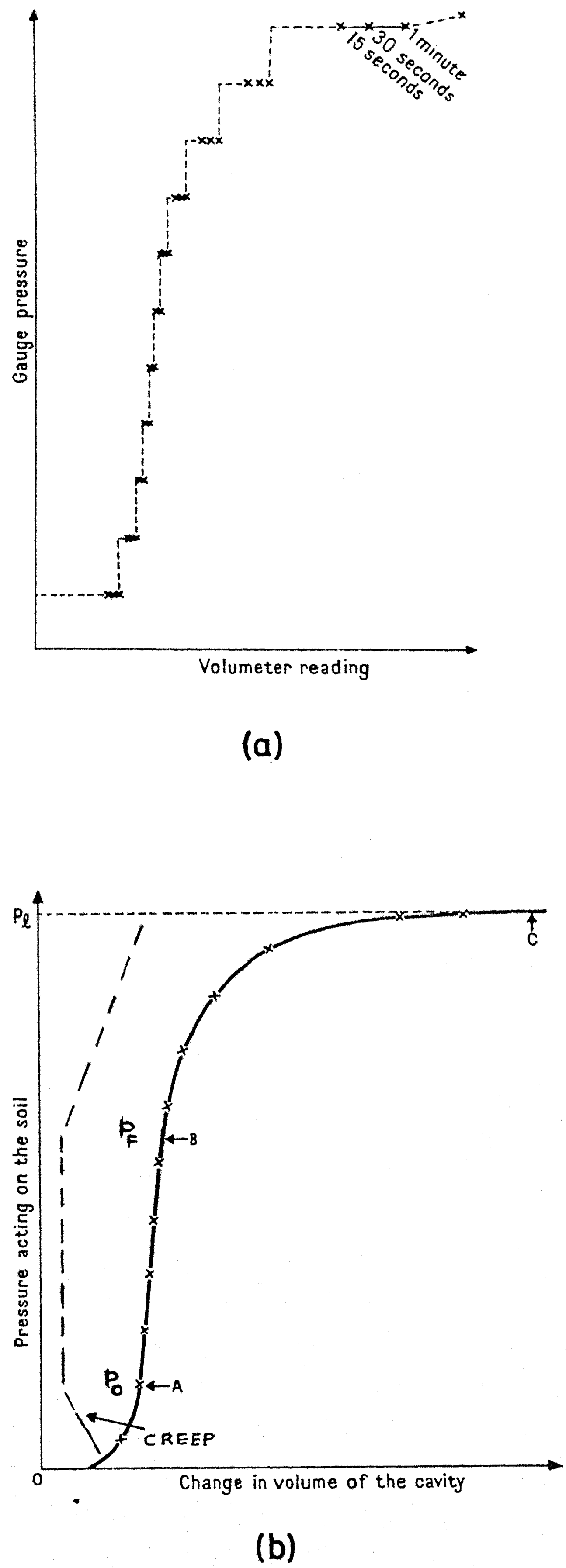
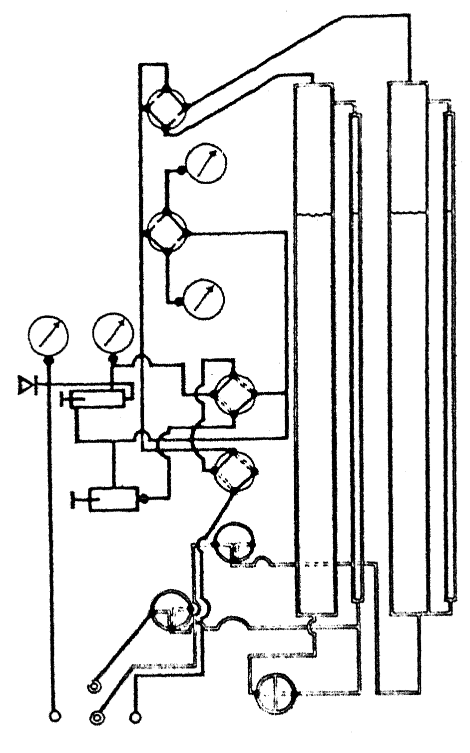
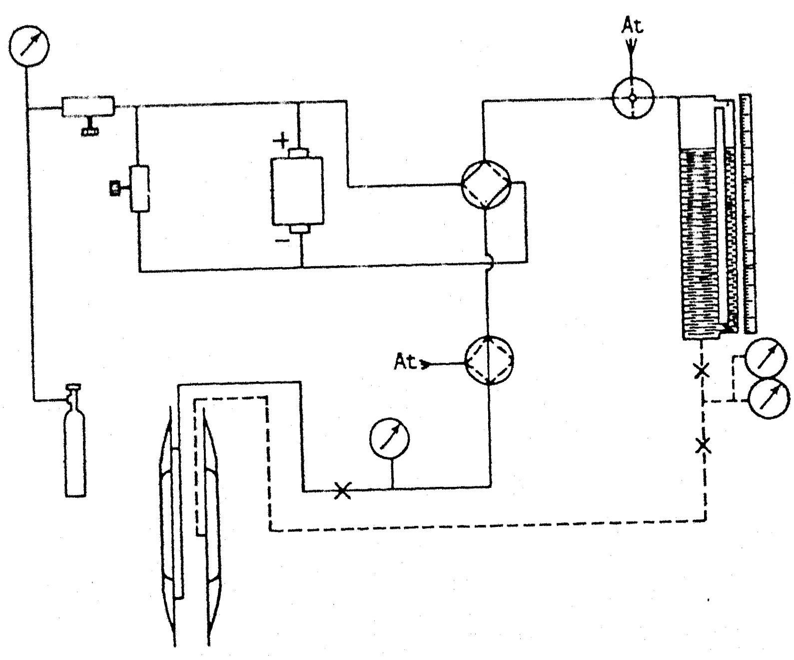


FIG. 1.2 TYPICAL PRESSUREMETER RESULTS



(a) GB TYPE



(b) GC TYPE

FIG. 1·3 HYDRAULIC CIRCUITS OF ME'NARD PRESSUREMETERS
(After Baguelin, 1978)

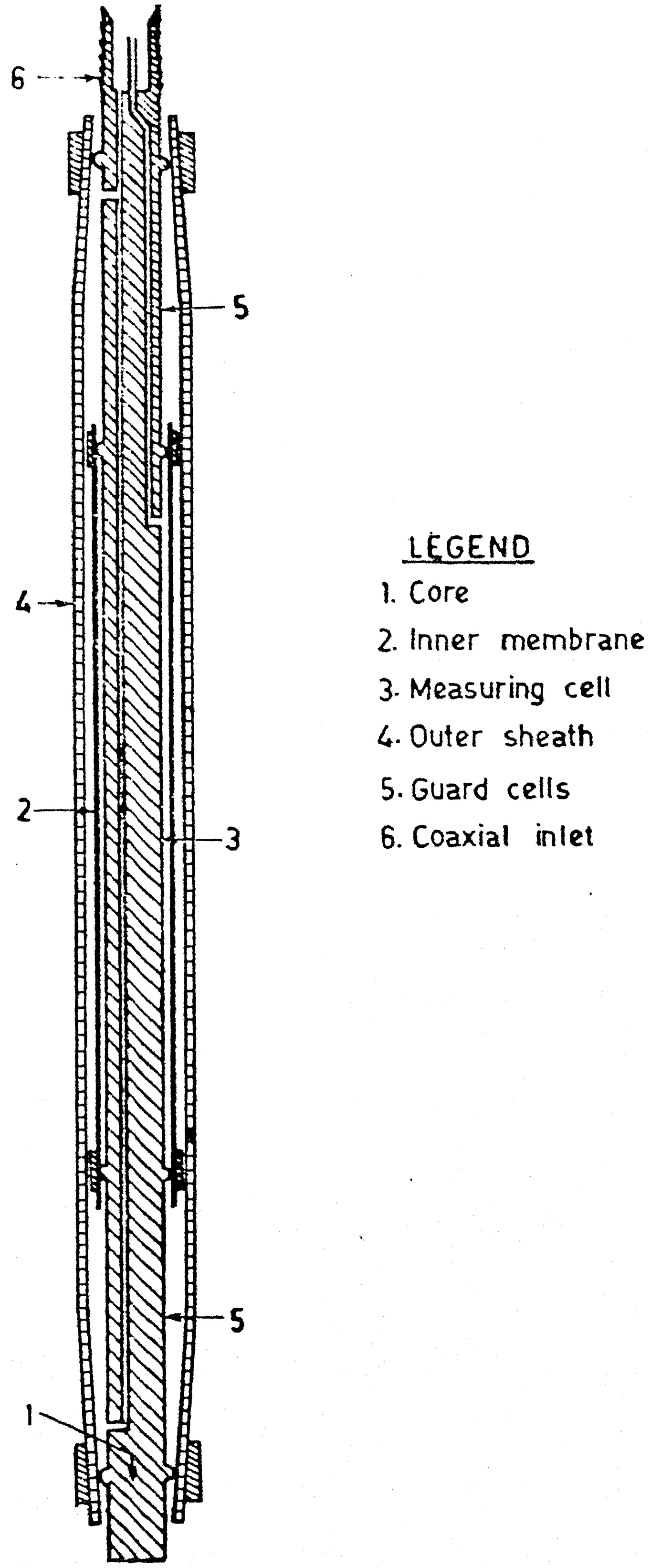


Fig. 1.4 Probe of Subsoil Deformeter

CHAPTER II

DESIGN AND OPERATION OF STRAIN CONTROLLED MONOCELL PRESSUREMETER

2.1 DESIGN SIMPLIFICATIONS ANS IMPROVEMENTS

Though the basic idea underlying the pressuremeter testing is very attractive, the test is not widely used all over the world. The fault lies, at least partly, with the apparent complexity of the Me'nard pressuremeter and its mode of operation. Over the years efforts have been made to identify and rectify various weak points of the original design. The major trends observed in this process of evolution are discussed in this section.

2.1.1 The Use of Monocell Probe

Basic aim of pressuremeter test is to create a plane strain condition around the borehole. This can be achieved only by a probe of infinite length. Thus in reality the condition during a pressuremeter test is somewhere between the expansion of a cylindrical cavity and the expansion of a spherical cavity. It was because of this reason that Me'nard introduced the 'guard cells'. While apparantly this was a change in right direction, it introduced various complexities in the design of the probe and surface unit for a marginal gain. A double hydraulic circuit is required to inflate the measuring cell and guard cells independently (Fig. 1.3). There is also a requirement of maintaining pre-calculated pressure difference between two type of cells in order to avoid seperation between them in GC type of probe.

Two studies could be found in literature regarding the effect of guard cells on the deformation pattern of borehole wall and on the values of parameters derived from the test. In France Saint Brieuc Laboratory of the Ponts et Chausseea (Baguelin et al.,1978) carried out pressuremeter tests at two sites with and without inflating the guard cells. The results for soft Cran clay and Cession loess are shown in Figure 2.1 Despite the small length to diameter (l/d) ratio of measuring cell (3.6 approx.), there didnot seem to be any significant difference in either E or P_L between the two tests. In another version of the test in Cran sand, test was carried out normally to a point halfway through the elastic phase. At this point the guard cells were deflated and the test was allowed to proceed. Again no significant difference in the results could be observed (Figure 2.2) before and after the guard cells were deflated. Finally number of series of tests was performed using BX size probe which had been modified into a monocell probe with l/d = 7.2 and the results were compared with standard tricell probe. Taking into account the heterogeneity of natural soil, no significant difference could be observed.

A model study using 1/3 reduced size scale models of monocell LLT probe and tricell Me'nard probe of GC type was made in Japan (Ohya et al., 1983). The expansion pattern of the probes were studied using radiographic technique. Radii calculated from the amount of water injected into the probe were compared with the radii measured from the X-Ray plates. The results are shown in Figure 2.3. Following were the findings of study:

(1) Expansion pattern of the probe within the ground is distorted at the ends of a monocell probe, but same is true about the

measuring cell of a tricell probe as well. The overall effect of this distortion is more pronounced for tricell probe because of its smaller l/d ratio.

(2) Considering the above fact it is only natural that calculated values of radii match more closely with the measured values for monocell probes.

(3) Distribution of displacement within the ground in vicinity of the centre of the probes matches closely with the results calculated using Finite Element Method (Figure 2.4 a).

Above discussion clearly shows that the guard cells in properly designed pressuremeter are quite unnecessary and can even have an adverse effect on the performance in certain cases. The realization of this fact has resulted into the adoption of monocell design in all modern pressuremeter devices. However, proper l/d ratio is of paramount importance in monocell probes in order to keep the error due to end restraint within acceptable limits. The problem of optimum l/d ratio has been studied theoretically by Hartman (Baguelin et al., 1978). Using elastic theory he concluded that in monocell probe l/d ratio of 8 is necessary to keep volume change measurements within 5% of those for an infinite cylinder. In addition to the high l/d ratio proper design of end clamps is required for monocell probes; otherwise unbalanced longitudinal force would cause the membrane to squeeze into the borehole. This can change the effective length of probe leading to errors in volume computation or even cause membrane to burst. However, simplifications resulting from elimination of guardcells are impressive.

2.1.2 Strain Controlled Testing

Most of the tests in Geotechnical Engineering are strain controlled tests in which the sample is deformed at a constant rate and the load required in doing so is measured. Failure condition is anticipated when the load level remains constant or drops with further straining.

Early developers of pressuremeter test not following this practice made it stress controlled test with a hope that it would simulate the condition of structural loading more accurately. Thus the pressure is applied in steps and volume change corresponding to a particular pressure is measured. This procedure has distinct disadvantages.

(1) Rapid load application followed by a short period of relaxation (1 to 2 minutes) creates complex drainage conditions around the probe.

(2) The rate of cavity expansion varies throughout the test and becomes too high towards the end of the test. This increases the risk of membrane bursting during last phase of the test.

(3) There are only few points (10 to 15) on the test curve particularly in elastic phase, making it difficult to interpret the test results.

(4) It is necessary to estimate limit pressure in advance so as to complete the test within specified time.

(5) It is difficult to introduce automatic data aquisition in this type of equipment.

It is possible to make the test strain controlled by injecting an incompressible liquid into a monocell or a tricell probe at constant rate and measuring the pressure at regular

intervals. Figure 2.5 shows few such mechanisms suggested by Baguelin et al., (1978). Mechanism shown in Figure 2.5 a is the simplest one and can be adopted safely if l/d ratio of the probe is large and expansion of flexible tube connecting the probe with surface unit is kept within limit.

Very few studies of comparison between Me'nard pressuremeter test and strain controlled test are reported in the literature. In one such study (Baguelin et al., 1978) single cell strain controlled probe having l/d ratio of 7.2 was used. Strain rate was selected so as to reach limit ressure in 10 minutes as required by the standard Me'nard test. Results for Cesson loess and Cran clay are shown in Figure 2.6. Referring to Figure 2.6 c, curve (a) is from standard Me'nard tests. In the later case a Me'nard test was simulated by strain controlled equipment (Section 2.3.3) considering the natural heterogeneity of soil, there are no significant differences among the test curves.

2.2 DESIGN OF CAVITY EXPANSOMETER

A pressuremeter incorporating the above discussed changes has been designed and built. Except the design philosophy the new equipment Cavity Expansometer (CAVITEX) is different from the models described in literature. The detailed design of any pressuremeter so far developed are not made available for maintaining the trade secret. As such, for designing CAVITEX all the details had to be conceived and implemented. The equipment is hand operated and can develope about 4000 KPa pressure without the aid of any external source of pressure like a carbon dioxide cylinder. Referring to Figure 2.7, CAVITEX can be divided into

two parts:

(1) Surface unit or control unit.

(2) Probe.

A short description of the important components along with their specifications is given below.

2.2.1 The Surface Unit

(A) CYLINDER:

Referring to Figure 2.8, the heart of the surface unit is a single acting hydraulic cylinder (1) having threaded ram (2). Specifications are as follows.

1. Design pressure - 5000 kPa.
2. Working fluid - water.
3. Bore diameter - 76 mm.
4. Wall thickness - 7 mm.
5. Stroke length - 220 mm.
6. Effective volume capacity - 1000 cc.
7. Sealing type - multiple 'o' ring.
8. Mounting type - Front flange.
9. Root diameter of ram - 25 mm.
10. Threads on ram - 1/4 inch pitch, single start, squar threads.
11. Weight - 15.5 kg.

The cylinder is hard chrome plated from inside to prevent corrosion. It was custom made by M/s Johnston Automation Ltd of New Delhi.

(B) DRIVING MECHANISM:

Referring to Figure 2.8, the threaded ram of cylinder passes through an internally threaded wormwheel (3) which bears against

a front plate (4). The water pressure acting on piston is transmitted to front plate via ram and wormwheel. Four studs (7) in turn transmit this axial force to the front flange of cylinder to maintain the equilibrium. Under the design pressure this load is about 22 kN. A worm supported by side plates (6) remains in contact with the wormwheel. The worm is connected to a mechanical counter which counts the number of revolutions of the former. The specifications for drive are as follows.

1. Number of teeth on wormwheel - 60.
2. Circular pitch of wormwheel - 1/4 inch.
3. Pitch diameter of wormwheel - 121 mm.
4. Worm - 1/4 inch pitch, single start.
5. Handle torque at full load - 2 kN - mm.

Cylinder and drive unit components are shown in Plate 2.

The piston can be driven at constant rate in one of the two modes. In the rapid mode the key (8) is lifted up and ram (2) is rotated by means of a handle to achieve a rate of 6.35 mm/revolution. A special joint between ram and piston prevents the rotation of the later. During the slow mode the key is inserted into a slot made in the ram and the worm is rotated to advance the piston at a rate of about 0.1058 mm/revolution. This corresponds to about 0.4801 cc/revolution and 0.0145 % radial strain/revolution or 0.0269 % volumetric strain/revolution. The volume corresponding to a particular pressure can be obtained by multiplying counter reading with least count (0.4801 cc/rev.). Worm speed and flow rates corresponding to different radial strain rate of 66 mm diameter probe are given below.

Strain Rate %/min	Flow Rate cc/min	Piston Velocity mm/min	Worm Speed rpm
0.3	10.69	2.356	22.3
0.6	21.41	4.720	44.6
0.9	32.16	7.090	67.0

While flow rate is kept constant, the radial strain rate drops constantly as the diameter of the probe increases. The volumatric strain and radial strain are related by the following equation

$$\frac{V}{V_o} + 1 = \left[1 + \frac{\Delta r}{a_o}\right]^2 \qquad 2.1$$

where, V = Volume injected

Vo = initial volume of cavity

Δr = change in radius

a_o = initial radius of cavity

However for small strains this change in strain rate is not very important.

(C) HUDRAULIC CIRCUIT:

The cylinder oulet (9) is connected to an alluminium manifold through a copper tube. Four ports are provided in the manifold. Referring to Figure 2.7, two 64 mm diameter, Burdon type pressure gauges (G1, G2) are connected to two ports. Gauges have capacity of 0-700 KPa and 00-2800 KPa respectively. Additional gauge can be provided if required. Inlet and outlet are provided through one port each. Four needle type regulatory valves (V1 to V4) are provided one at each port. The assembled circuit is shown in Plate 3.

The cylinder and the drive unit shown in Figure 2.8 are mounted on a steel frame of 50x30x18 cm dimension. The complete surface unit without external covering is shown in Plate 4. Total weight of surface unit is about 25 kg.

2.2.2 The Probe

The monocell probe is shown in Figure 2.9. A central pipe (7) threaded at both the ends (2), forms the back bone of the probe. The outer pipe (8) is covered with a rubber membrane (9) which is folded inside at both the ends. The rubber membrane was manufactured by M/S Saroja Rubber Ind. of Baroda at special request. Two thrust caps (3) screwed on the central pipe press the membrane against outer pipe thereby forming a water tight seal at the ends. Rubber membrane is covered with 16 overlapping stainless steel strips (10) tucked by screws (4) on the thrust caps. The jacket formed by these strips prevents the rubber membrane from being punctured by sharp objects at the same time offers negligible resistance to the expansion. Longitudinal expansion of membrane is prevented by two semi-flexible end caps (5). Inlet (1) is connected to the outer pipe by a copper tube (6). The probe has been kept hollow to prevent the piston action taking place when it is lowered into a borehole filled with water. The specifications are as follows.

1. Minimum diameter 66 mm.
2. Maximum diameter 83 mm (corresponding to about 25% radial strain)
3. Total length 700 mm
4. Effective length 520 mm (l/d ratio of 7.88)
5. Thickness of rubber membrane 2 mm
6. Type of rubber - Natural

7. Thickness of steel jacket - 0.5 mm

8. Overlap of strips - 6.8 mm

9. Weight of probe 6.175 kg

Various components of probe are shown in Plate 5

2.2.3 Fabrication and cost aspecs

Most of the components of the surfacee unit and the probe were made either in Civil Engineering department workshop or in Central Workshop of IIT/K. The fabrication was done in the departmental workshop. From a rough estimate, the manufacturing cost of the complete equipment works out to be about Rs. 7000 only. This is extremely cheap in comparison with the Borehole Deformeter marketed by AIMIL India at a price of about Rs. 100000.

2.3 OPERATION OF CAVITEX

2.3.1 Deairing of Circuit

A thorough deairing is required as presence of air bubbles in the circuit would result into volume losses. However, small quantity of air may be tolerated and can be taken into account through calibration process (section 2.3.2). The control unit is deaired in following steps.

(1) Referring to Figure 2.7, valves V_2, V_3 and V_4 are closed. The key is lifted up and piston is moved back by turning threaded ram. During this process water is poured at inlet (I) through a funnel.

(2) Piston is moved rapidly in forward direction to remove air bubbles present in the circuit.

(3) The process is repeated several times keeping V_1 and V_2 open alternately.

(4) When the circuit is deaired the cylinder is completely filled up with water and the key is inserted back.

Flexible hydraulic hose connecting surface unit with probe is deaired seperately by siphoning and connected to the outlet (O). Probe is deaired by injecting small quantity of water under pressure through a nozzled bottle. It is preferable to check during whenever the circuit is subjected to high vacuume.

2.3.2 Calibration

Accurate calibration of any pressuremeter is required to obtain the corrected pressure-volume curve. There are essentially three kind of errors to be taken into the account during calibration process.

(a) Volume Losses:

Various volume losses are inherent in any pressuremeter because of flexibility of hydraulic cable, compression of rubber membrane, compliance of pressure gauges, presence of small quantity of air etc. Calibration for volume losses in CAVITEX is done by inserting the probe into a close fitting, thick walled steel tube. The probe is expanded and volume corresponding to different pressure is noted. A typical calibration curve is shown in Figure 2.10. Because of the space between the probe and the steel tube and the resistance of membrane, it takes certain volume and pressure to inflate the probe before it comes in contact with steel tube. In Figure 2.10 good contact between steel tube and probe can be assumed at 400 KPa pressure. At pressures greater than this, volume losses in control unit, hydraulic cable and probe are measured. To measure volume losses for pressures below contact pressure, the straight line portion of the curve can be

extended back. However, this method tends to underestimate the correction. Volume losses in low pressure range can be obtained by calibrating control unit and hydraulic cable without probe as shown in Figure 2.11 . A composite curve drawn using the method suggested by Baguelin et.al. (1978) is shown in Figure 2.12,and represents the final correction to be applied. For CAVITEX volume correction in properly deaired circuit is few cc and can be neglected in normal soil condition. However, volume correction becomes very important in stiff clays or very dense sands where even a small error in volume measurement can affect modulus appreciably.

(B) Pressure losses:

The actual pressure transferred to the soil during a pressuremeter test is always less than pressure inside the probe. This is because some pressure is required to inflate the probe and metallic sheath. Thus, a membrane correction is necessary. This is done by expanding the probe in the air and measuring pressure at different volumes. Calibration should be done at the same strain rate used in actual testing. A typical pressure correction curve for CAVITEX is superimposed on similar curves, for Menard pressurementers in Figure 4.13 after Baguelin et.al. (1978). It can be seen that pressure correction for CAVITEX is small compared to other pressuremeters. Since the expansion pattern of probe during air calibration is totally different from that during actual testing, this method of pressure correction is only aproximate. A more refined method is discussed by Murat and Lemoigne (1988). Pressure correction is very important for tests conducted in soft clays.

Both volume and pressure calibration should be carried out before starting of any test series and after every important change in the probe like replacement of membrane.

(c) Absolute calibration:

An absolute calibration is necessary to check instrumental accuracy. Pressure gauges were checked against the master gauge of a triaxial test apparatus. Piston movement was measured by a dial gauge for fixed number of revolution of worm. It is impossible to avoid some amount of play in any gear system. For cyclic tests this play should be measureed and correction should be applied whenever the direction of piston is changed.

2.3.3 Test Procedure

Once the hydraulic circuit is deaired and the cylinder is charged with water, valve V_1 is closed and probe is lowered into the borehole at desired depth. Valves V_2, V_3 and V_4 are opened subjecting the circuit to a vacuume pressure equal to the hydrostatic head between the surface unit and the probe. Counter is set to zero reading and worm is rotated in forward direction at a constant speed. The counter is immediately read when positive pressure builds up in the circuit. After that readings are taken at constant pressure difference until volumatric capacity of the cylinder is reached.

It is also possible to simulate Me'nard type test with a strain controlled equipment. The desired pressure is build up rapidly by turning the worm and kept constant for 1 minute. Volume reading are taken at 15, 30 and 60 seconds. Next increment is applied at the end of this time interval.

2.4 SPECIAL FEATURES

In addition to the inherent advantages of strain controlled, monocell design as enunciated in Section 2.1, CAVITEX incorporates the following special features.

(1) No rubber 'O' ring is used to seal the ends of the membrane which itself acts as a sealing member. This provides good grip at the ends and reduces the risk of membrane being pulled out during the test. Also the replacement of damaged mmbrane is straight forward and can be done within short time.

(2) Use of metallic jacket instead of thick rubber sheath to protect the rubber membrane. This provides good protection with very low resistance to expansion (Figure 2.13). Individual strip is screwed separately which makes replacement of any damaged strip very easy. This method of fixing jacket is superior to the friction grip as risk of jacket being pulled out of its grip during hard extraction of probe is eliminated.

(3) There is no gap bettween the membrane and the outer pipe in uninflated condition. Therefore, there is no trapping of air in the probe or no risk of collapse of the membrane in a squizzing borehole.

(4) There are very few moving parts making the maintenance very easy. There is nominal play in the gear system.

(5) Hydraulic circuit is kept very simple making it easy to be desired. There are only about 14 joints as compared to more than 50 joints in the circuit of SUBSOIL DEFORMETER. There are less hydraulic losses and less chances of leakage and error in reading.

2.5 DRAWBACKS

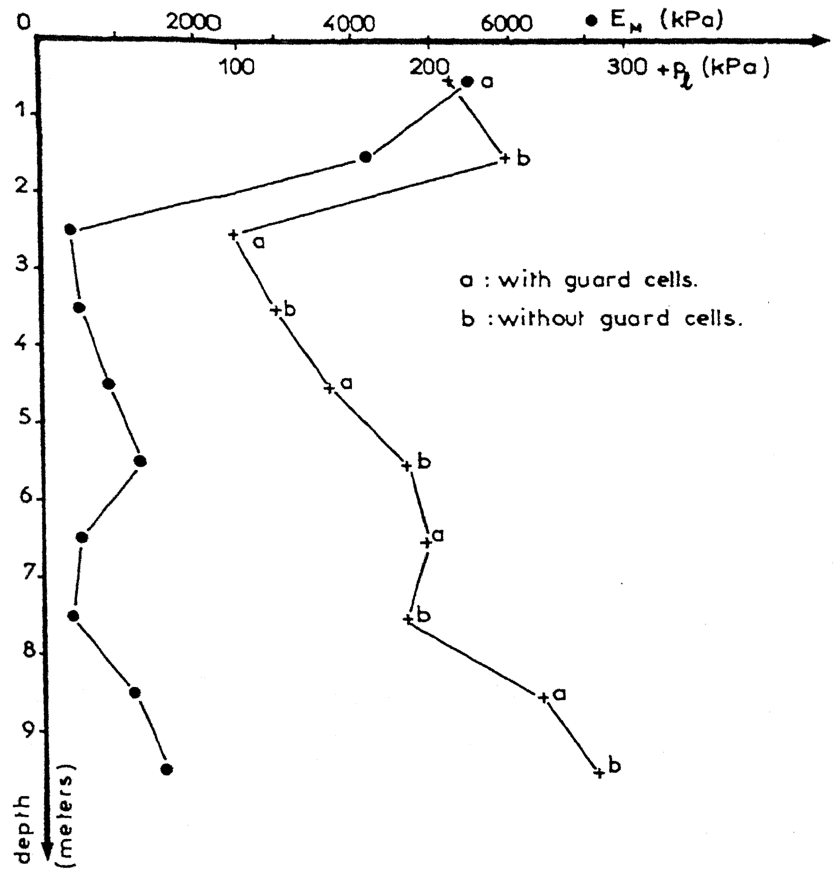
Following are the drawbacks of CAVITEX as compared to a Me'nard type pressuremeter.

1. Deairing of hydraulic circuit and connecting cable is very critical. Similarly presence of small leakage can affect results considerably particularly in stiff soils. However, experience has shown that consistant deairing can be obtained with little care and patience.

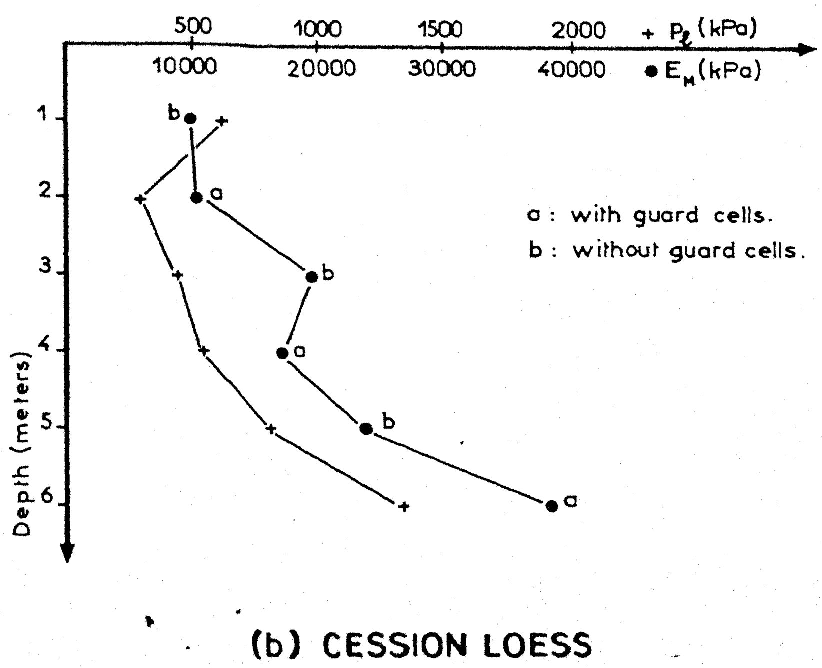
2. In Me'nard type devices volume loss due to expansion of hydraulic cable is extremely small since pipe carrying water to measuring cell is surrounded by another pipe carrying gas to guard cell. In CAVITEX use of single hydraulic cable increases the volume losses due to expansion of cable. However, proper calibration at working temperature can solve the problem.

3. The test is carried out in a continuous manner and no 'creep' readings are taken. Thus interpretation of p_o and p_L is to be done solely from the shape of pressure- volume curve.

4. Monocell probe cannot be expanded to high strains (more than 30%) without the risk of membrane bursting. Also at high strains, the shape of expanded probe departs considerably from cylindrical pattern (Figure 2.4 b). Thus maximum radial strain is limited to about 25% and results have to be extrapolated to 41.4% strain in order to obtain limit pressure.



(a) CRAN CLAY



(b) CESSION LOESS

FIG. 2-1 EFFECT OF REMOVING GUARD CELLS (After Baguelin, 1978)

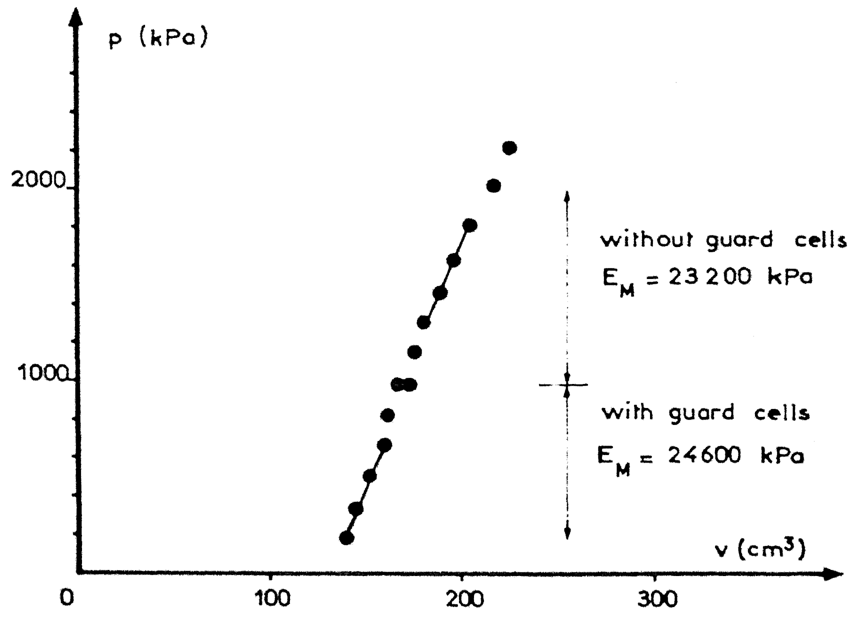


FIG. 2-2 EFFECT OF DEFLATING GUARD CELLS IN CRAN SAND (After Baguelin ,1978)

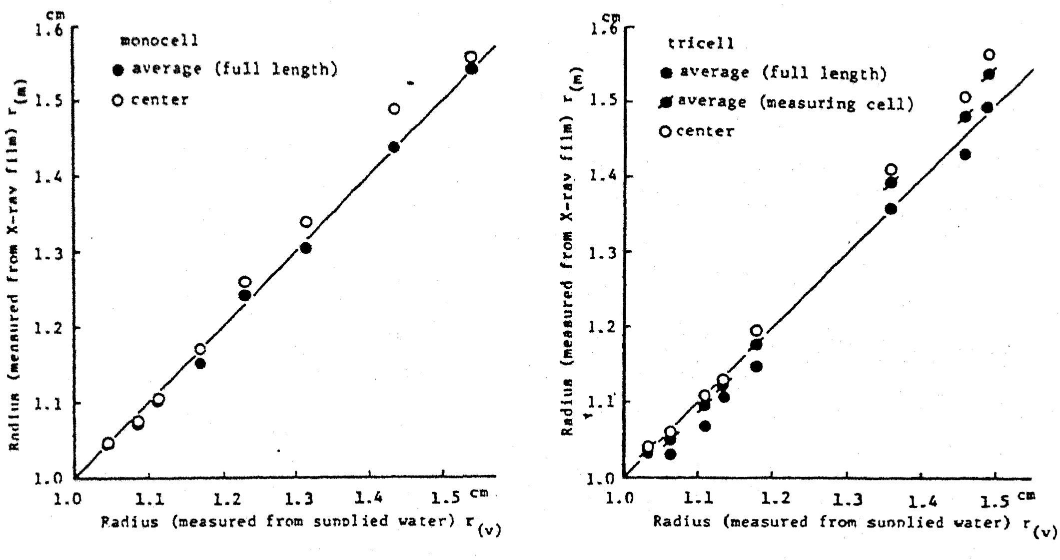
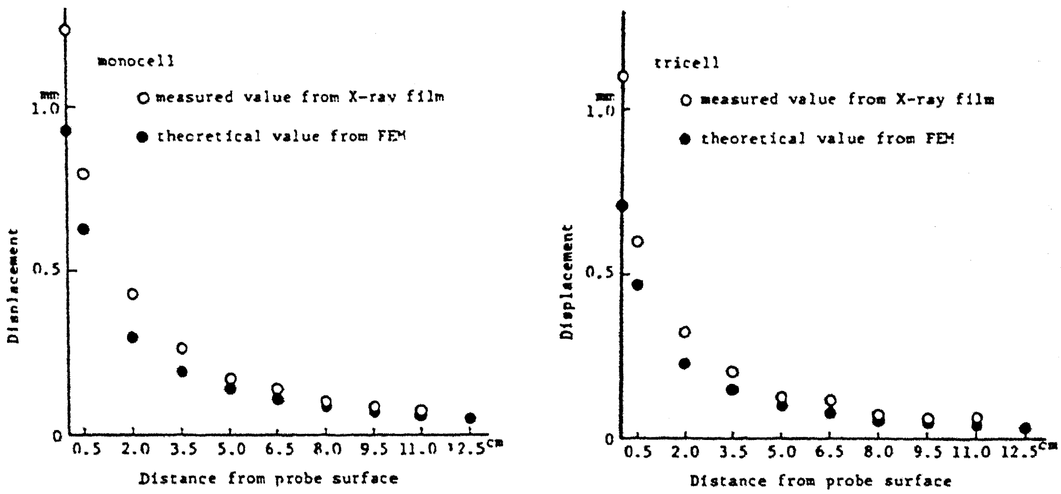
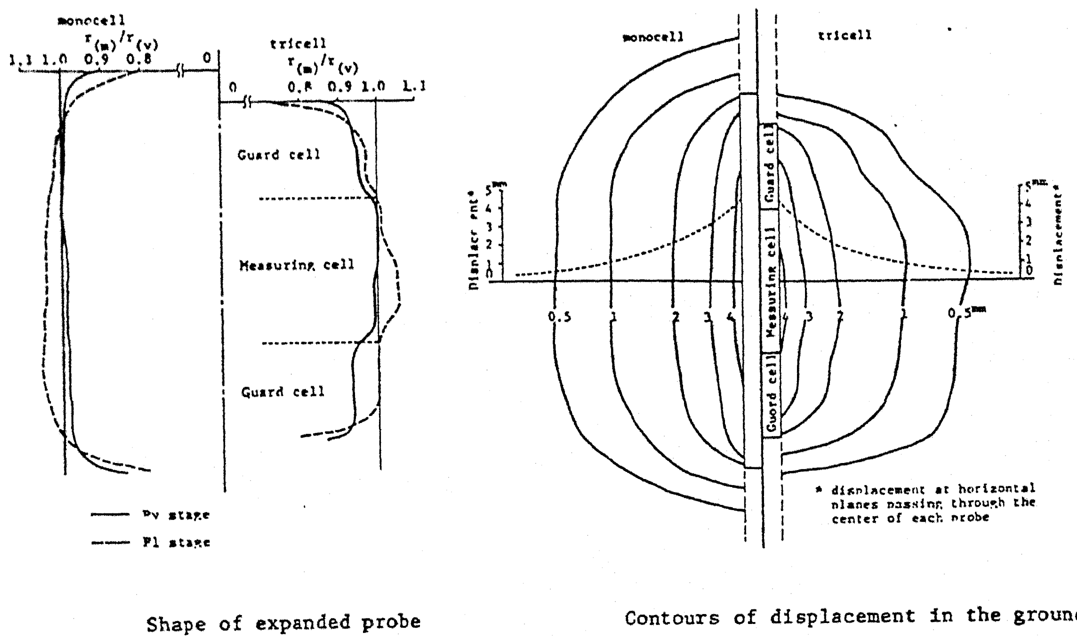


FIG. 2-3 MEASURED RADII FROM SUPPLIED WATER AND X-RAY FILM (After Ohya ,1983)



(a)



(b)

FIG. 2-4 GROUND DISPLACEMENT PATTERNS AROUND MONOCELL AND TRICELL PROBES (After Ohya, 1983)

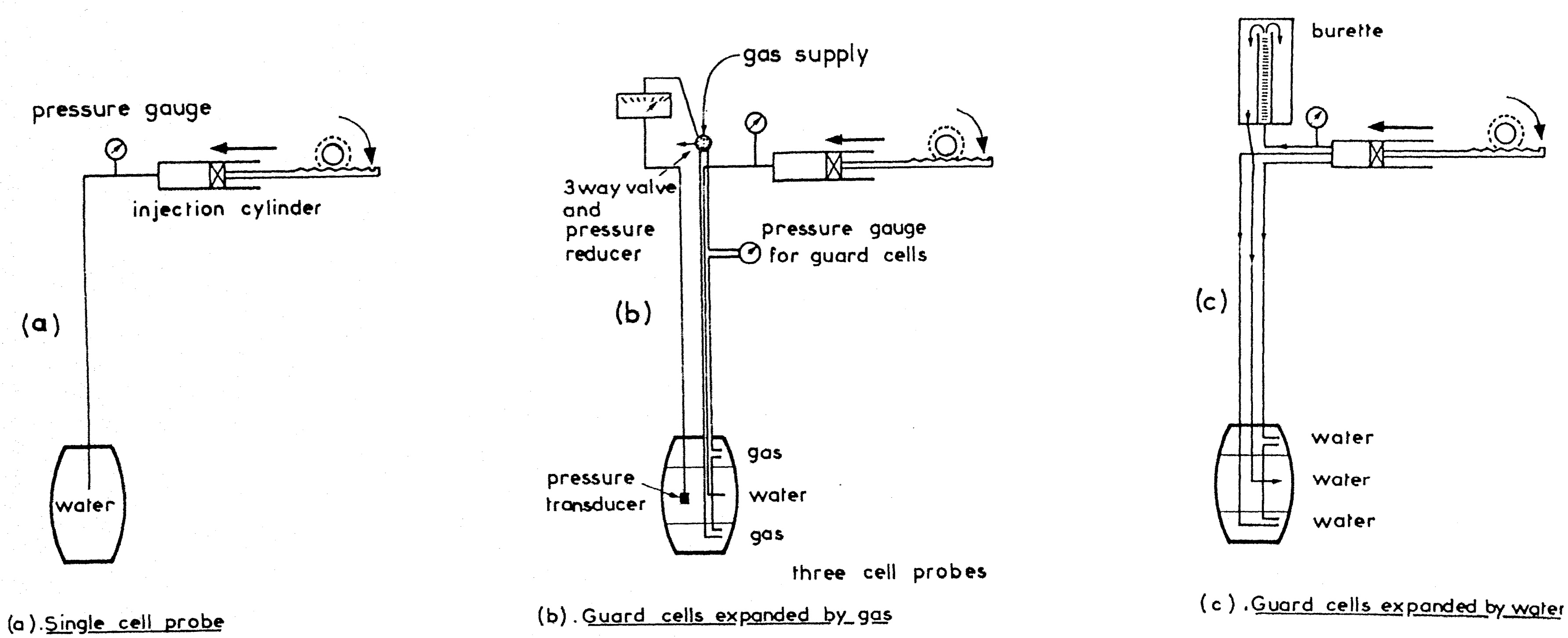
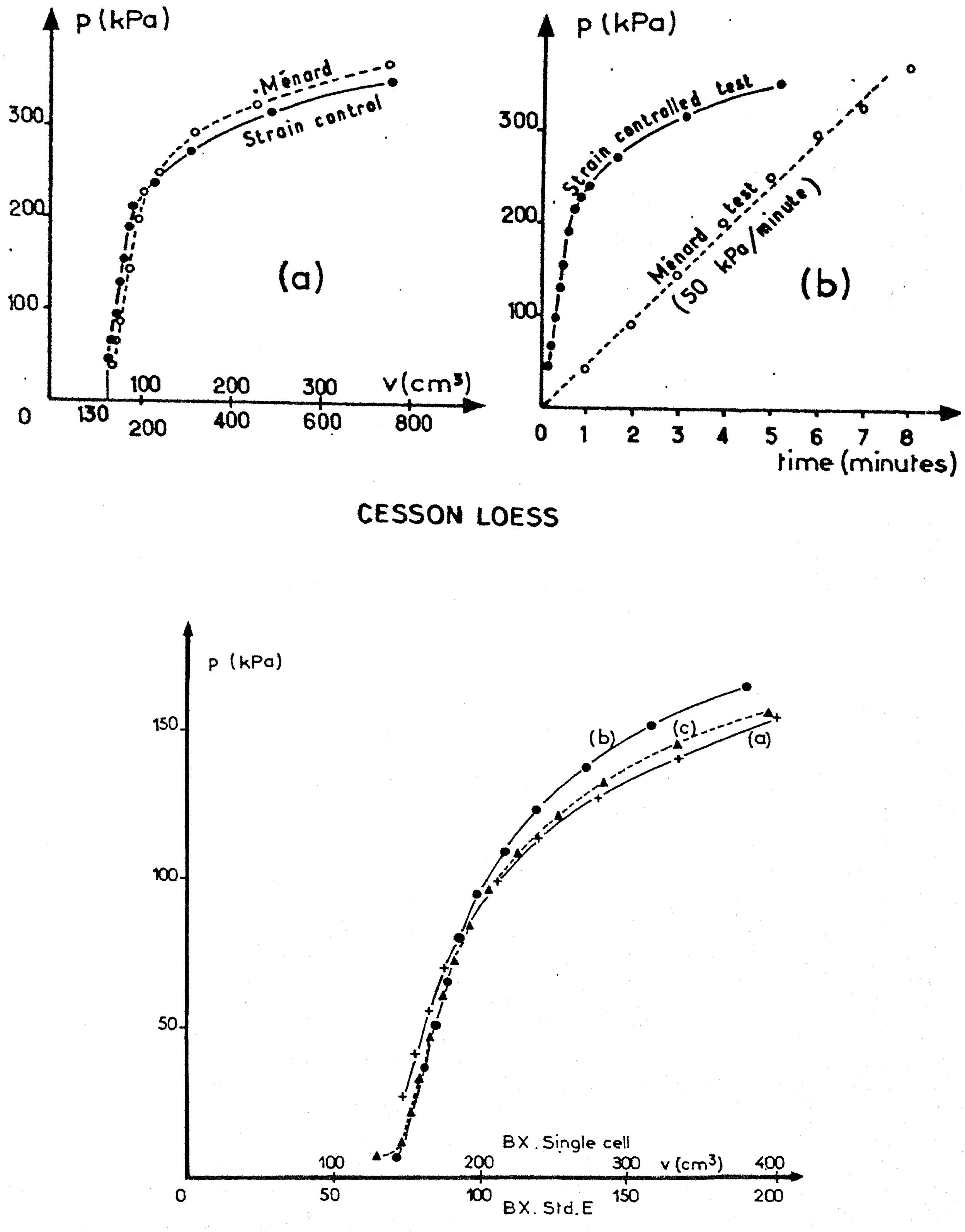


FIG. 2.5 MECHANISMS FOR STRAIN CONTROLLED PRESSUREMETAR
(After Baguetin, 1978)



(c) CRAN CLAY

FIG. 2-6 COMPARISON BETWEEN MEANRD TEST AND STRAIN CONTROLLED TEST (After Baguetin, 1978)

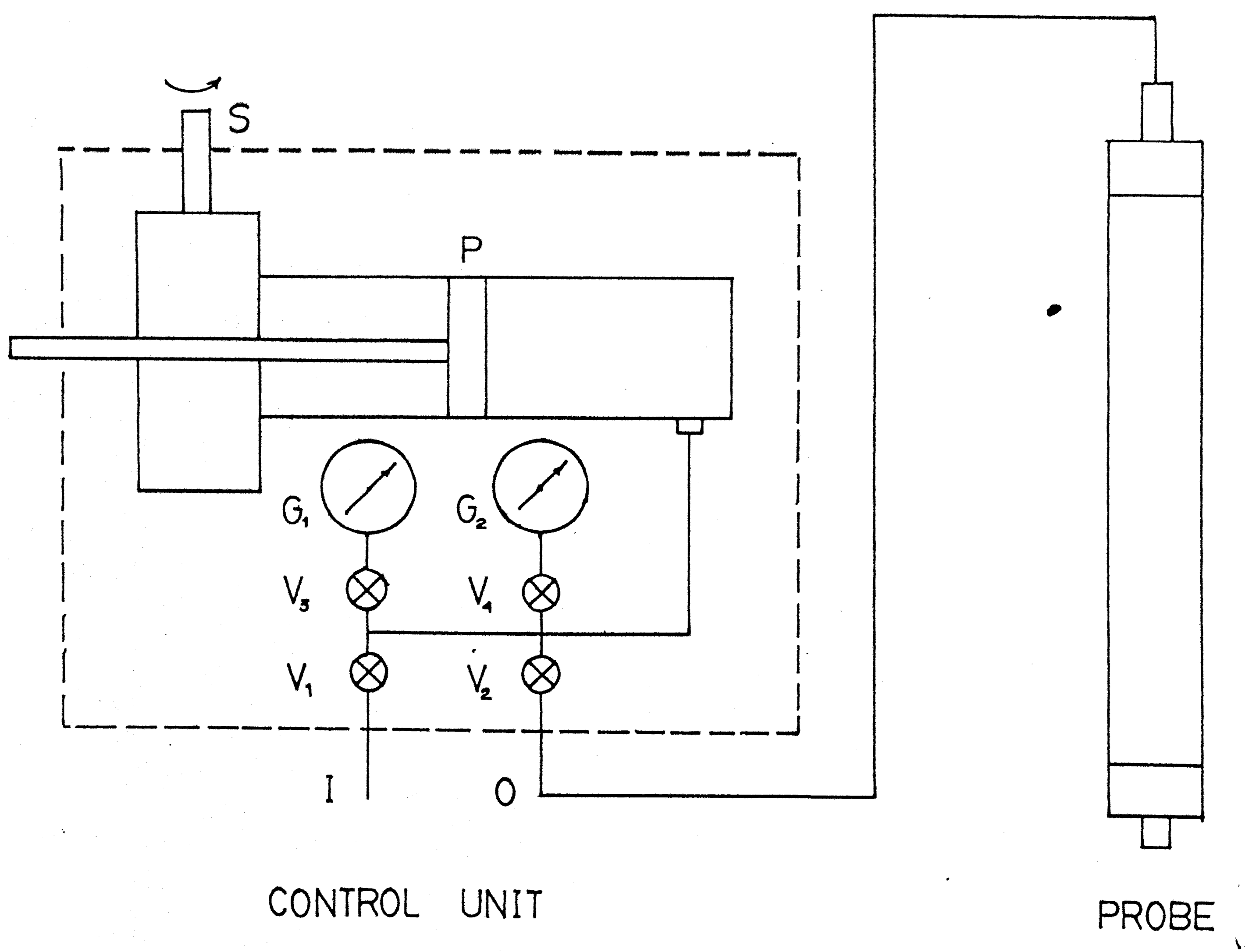
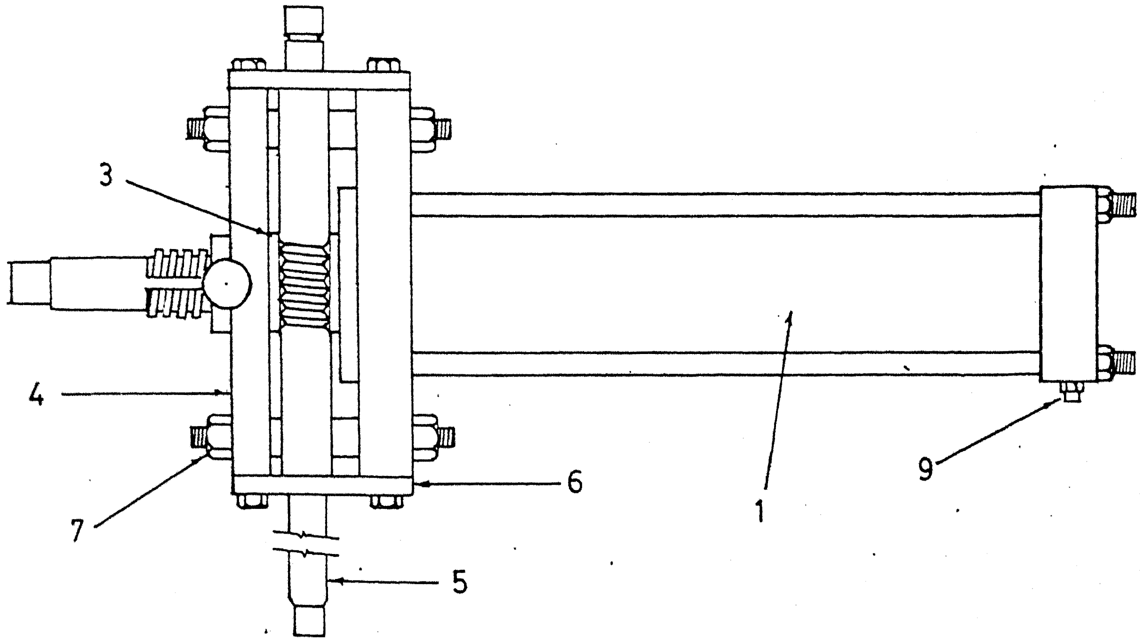
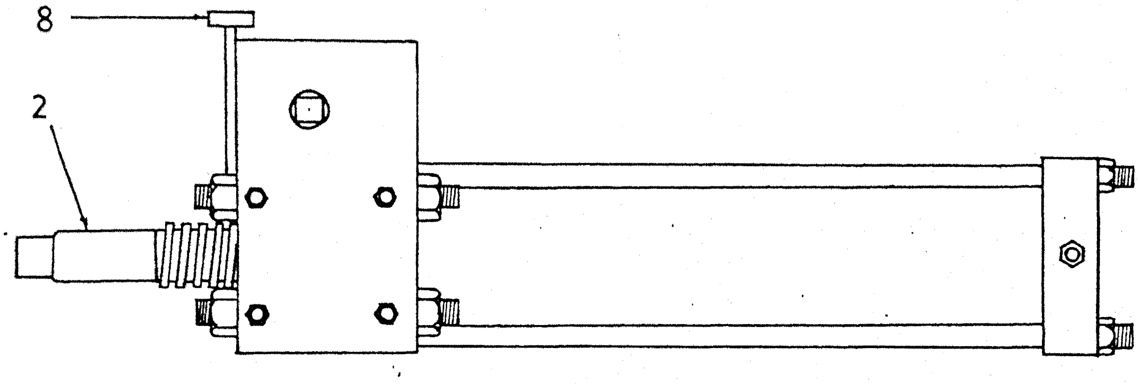


FIG. 2·7 SCHEMATIC DIAGRAM OF CAVITEX

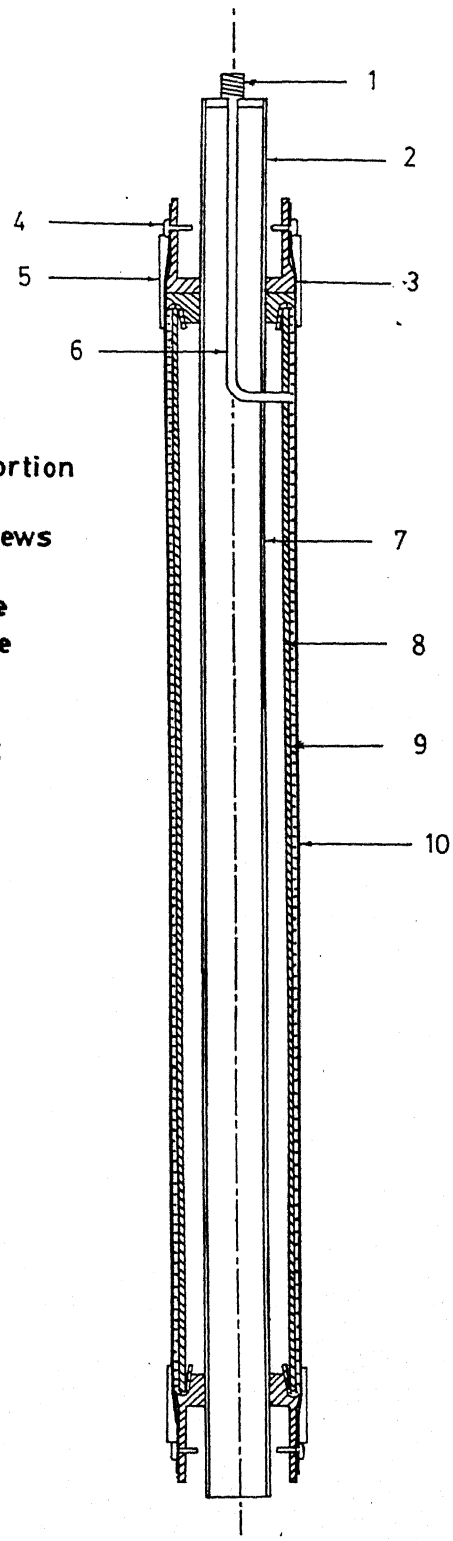


PLAN



ELEVATION

FIG. 2.8 PISTON DRIVING MECHANISM



LEGEND

1. INLET
2. Threaded portion
3. Thrust cap
4. Tucking screws
5. End cap
6. Copper pipe
7. Central pipe
8. Outer pipe
9. Membrane
10. Steeljacket

FIG. 2-9 THE MONOCELL PROBE

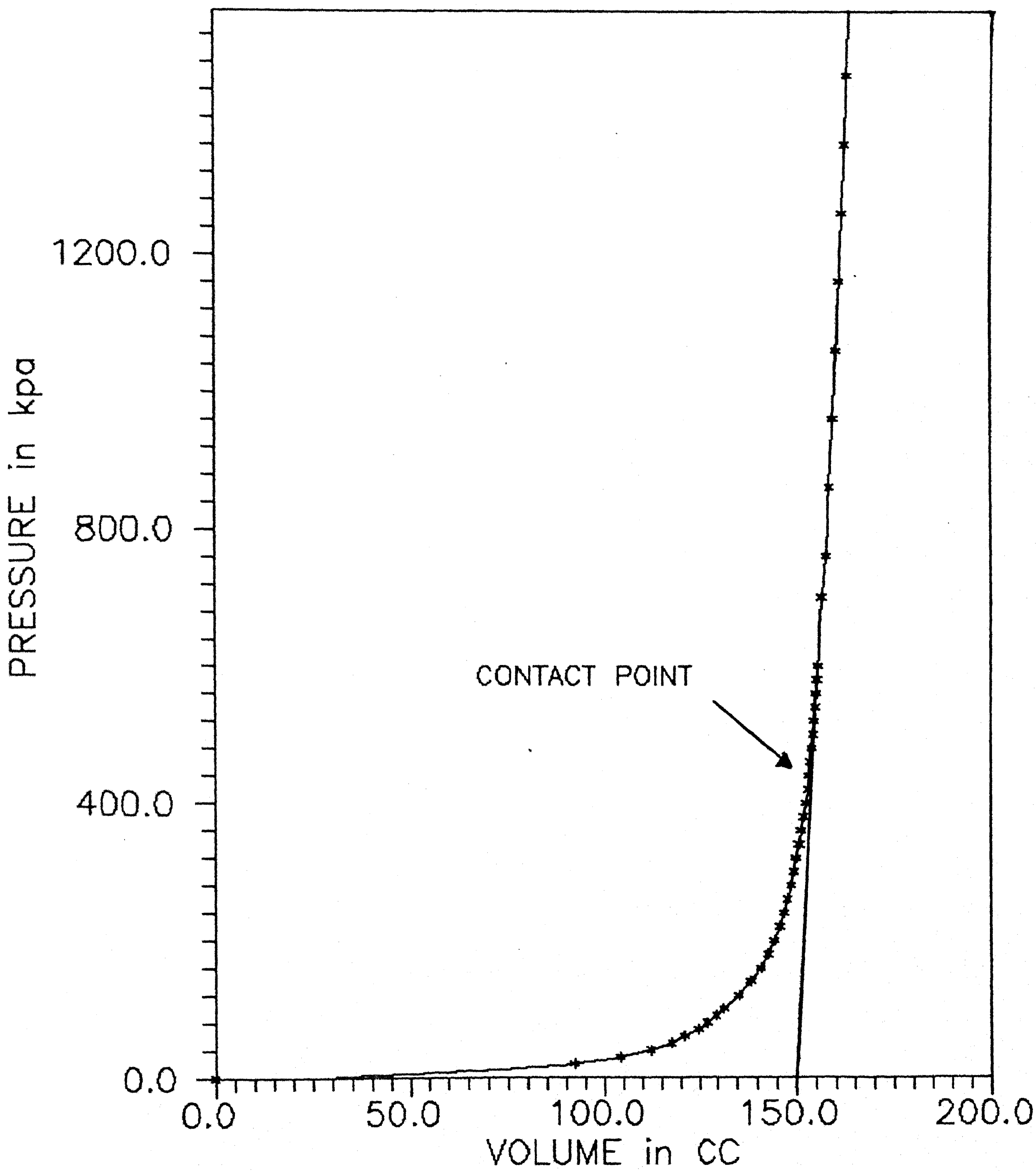


FIG. 2-10 VOLUME CALIBRATION WITH PROBE INSIDE STEEL TUBE

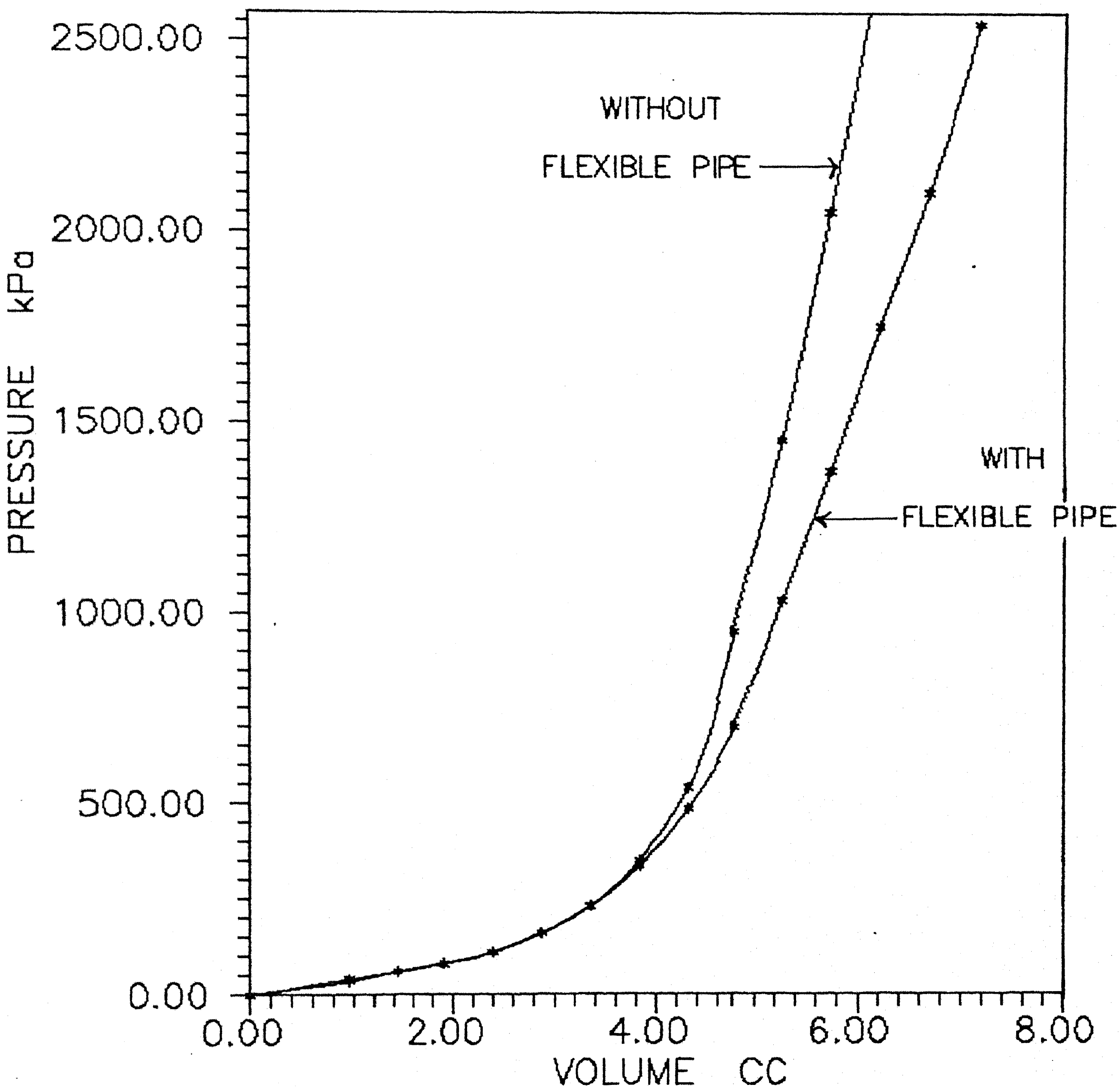


FIG. 2.11 VOLUME CALIBRATION WITHOUT PROBE

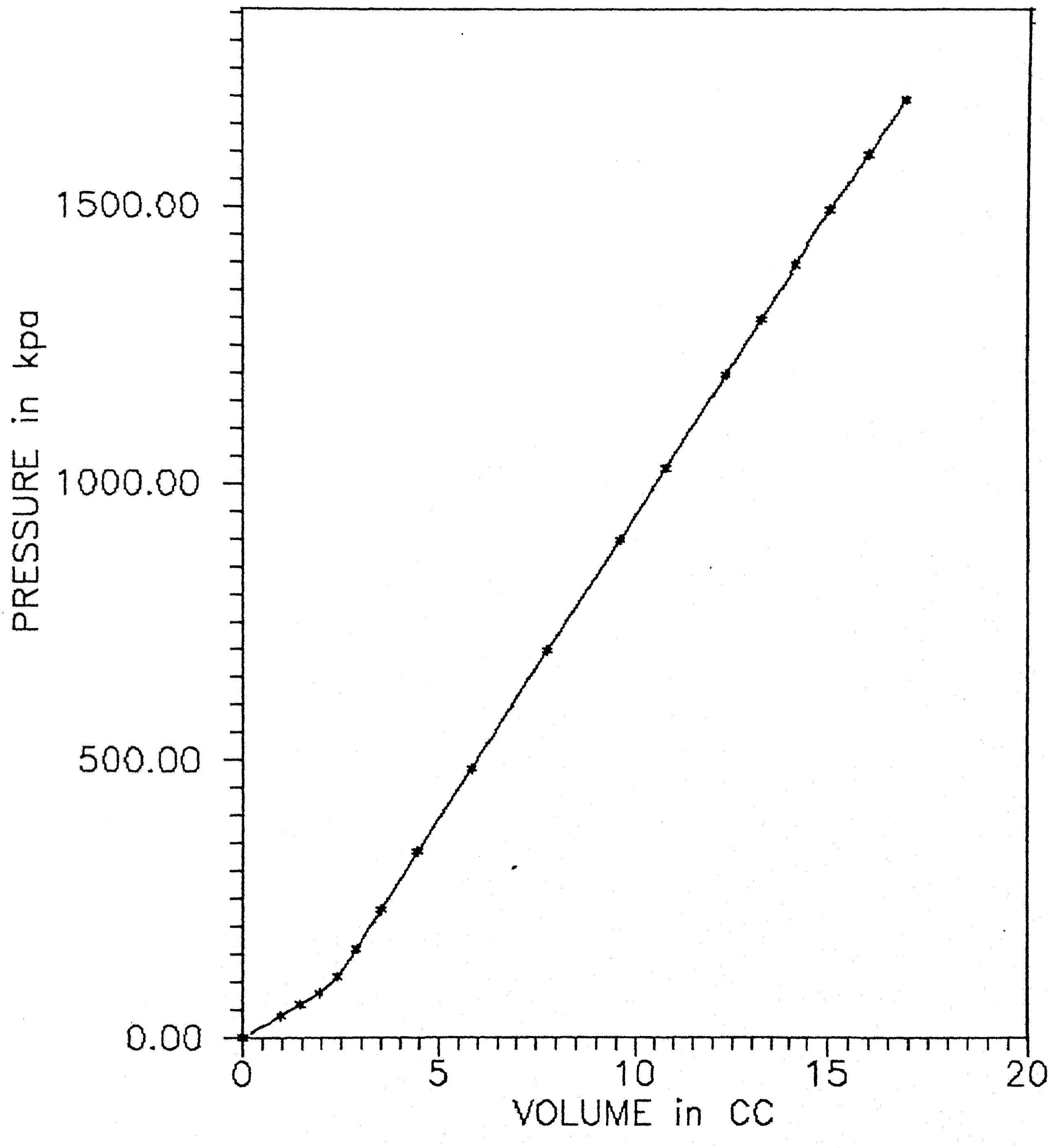


FIG. 2.12 VOLUME CORRECTION CURVE

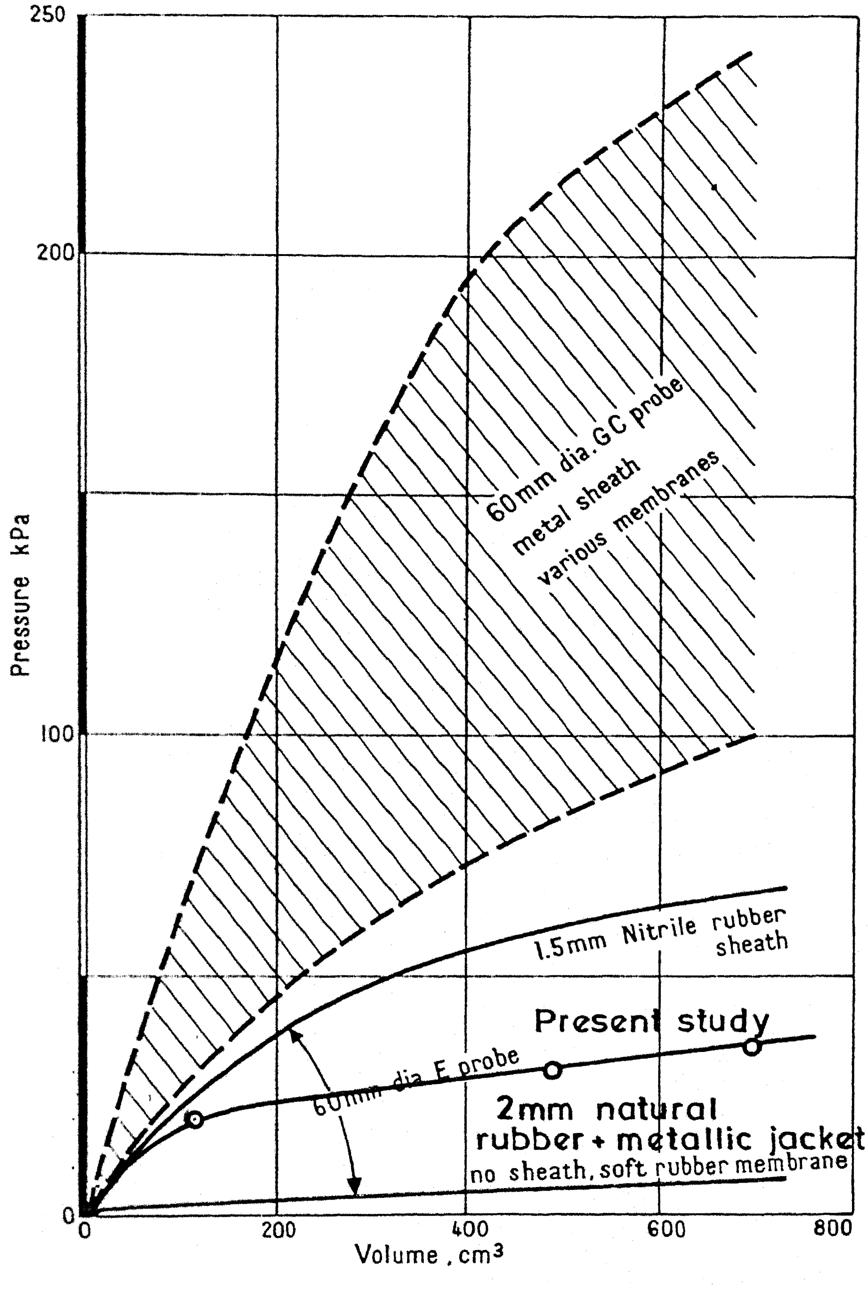


FIG. 2·13 MEMBRANE RESISTANCE OF VARIOUS PROBES (After Bageuelin, 1978)

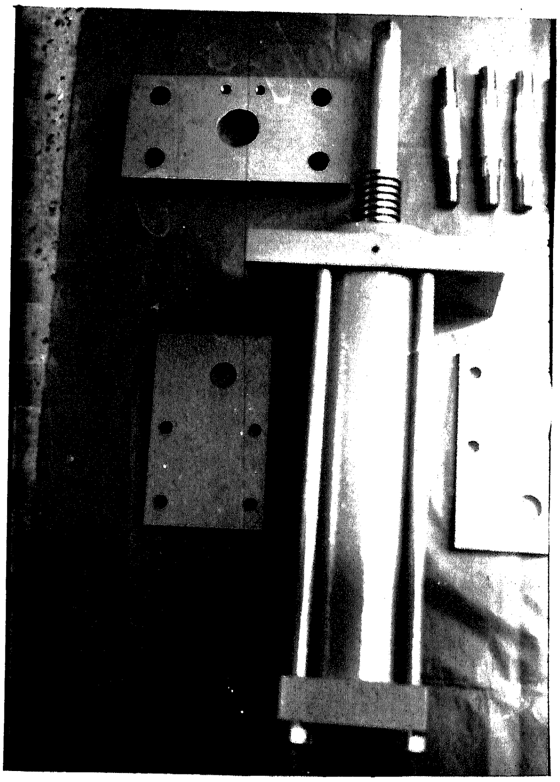


Plate 2

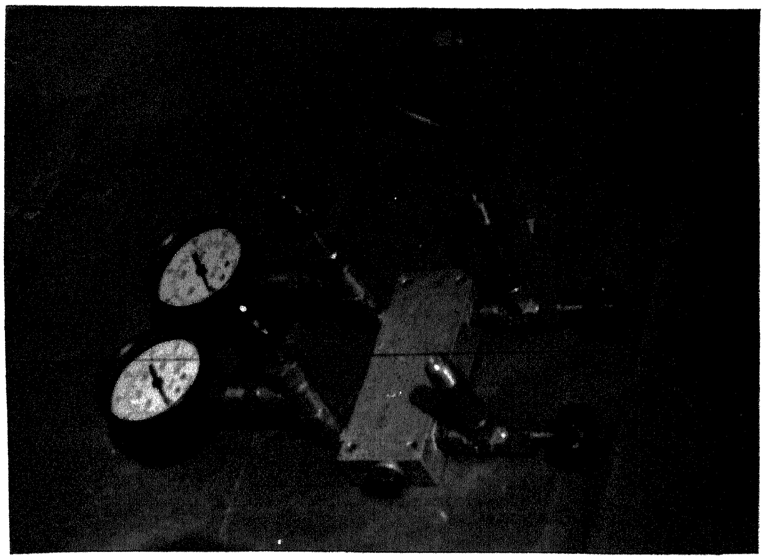


Plate 3

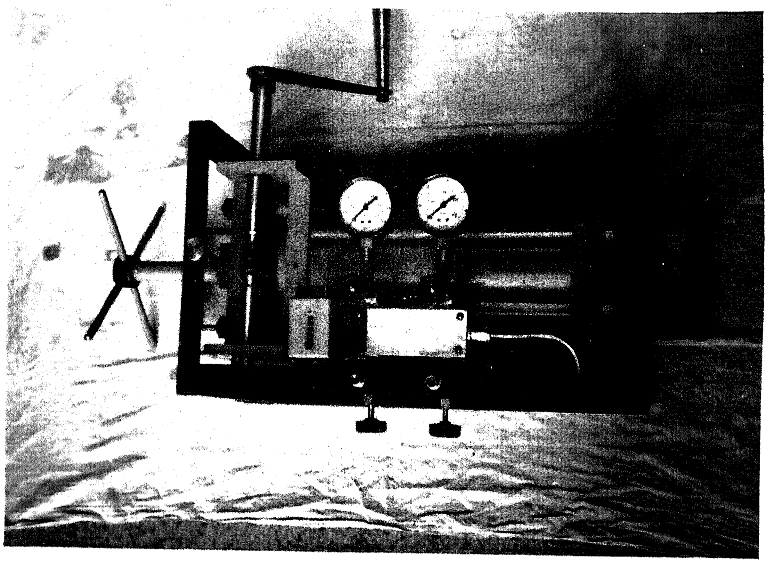


Plate 4

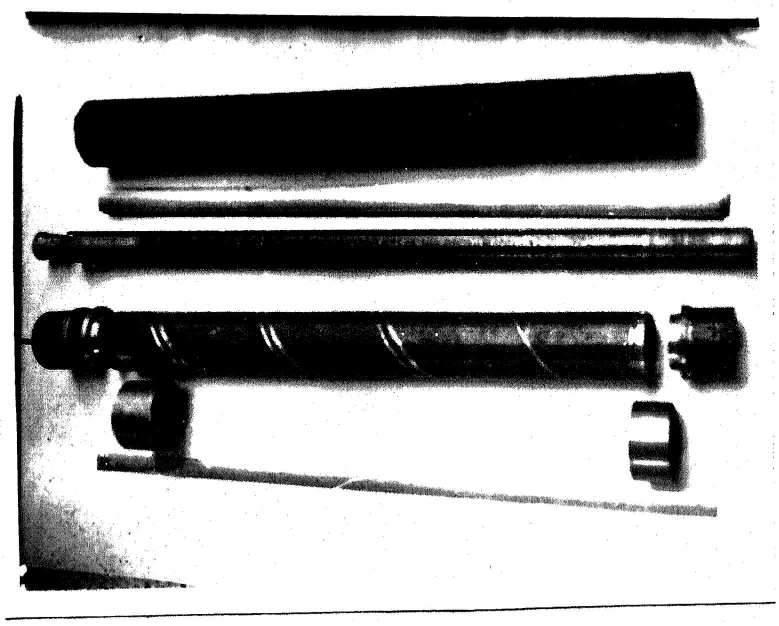


Plate 5

CHAPTER III

THEORIES OF PRESSUREMETER TEST

3.1 GENERAL

Pressuremeter test is the only field test which can be analysed rigorously assuming almost any stress-strain model and efforts have been made to do so over the last 30 years. The work which is relevant to the prebored pressuremeter (PBP) test is presented in this chapter; complete treatment of the subject can be found in literature.

Two basic assumption are made in all theories of pressuremeter test.

(i) The test simulates the expansion of infinitely long cylindrical cavity. Thus end effects due to membrane griping are neglected.

(ii) Soil surrounding the probe is in undisturbed condition at the onset of the test.

3.2 ELASTIC MODEL

When deformations are small most soils can be idealized as elastic material. Following points can be noted.

(i) Because the cavity is infinite, the deformations in vertical direction are zero and plane strain condition is obtained in a plane perpendicular to the axis of the cavity.

(ii) Because the cavity is cylindrical, the soil is deformed under a condition of axial symmetry. As a result of this the stresses in radial, circumferential and vertical directions are principal

stresses and all deformations are radial.

Equation of equilibrium for such a condition can be written as

$$\frac{d\sigma_r}{dr} + \frac{\sigma_r - \sigma_\theta}{r} = 0 \qquad 3.1$$

Where σ_r - radial stresses,

σ_θ - circumferential stresses,

r - distance in radial direction.

If η is the outward radial deformation at radius r (fig 3.1b), the circle which had circumference of $2\pi r$ now has circumference of $2\pi(r + \eta)$ and circumferential tensile strain becomes

$$\epsilon_\theta = \eta/r. \qquad 3.2$$

If η varies with the radius then radial strain is given by

$$\epsilon_r = \frac{d\eta}{dr} \qquad 3.3$$

Following boundary conditions apply

(i) At the wall of cavity radial stress is p and radial displacement is η_c.

(ii) At infinity total radial stress is equal to the insitu horizontal total stress p_o and radial displacement is zero.

Using elasticity it can be proved that the radial and circumferential strains are equal and opposite and vary inversely with the square of the radius:

$$\epsilon_\theta = -\epsilon_r = \eta_c a/r^2 \qquad 3.4$$

Where a is radius of cavity at any stage.

Thus deformation takes place at constant volume. The

stresses around the cavity also vary inversely with the square of the radius:

$$\Delta\sigma_r = -\Delta\sigma_\theta = \frac{2G \epsilon_c a_o a}{r^2} \quad 3.5$$

Where

$\Delta\sigma_r$ = change in radial stress.

$\Delta\sigma_\theta$ = change in circumferential stresses.

G = shear modulus.

a_o = initial radius of cavity.

ϵ_c = cavity strain defined as η_c/a_o.

Thus radial and circumferential stresses change by equal and apposite amount from in-situ horizontal stress p_o and the octahedral stress remains constant. Thus the expansion of cavity which appears a compressive process is, in reality, a pure shearing process and no excess porewater pressures are developed in elastic phase of the test. Shear modulus G during this phase is obtained as

$$G = \frac{1}{2} \frac{dp}{d\epsilon_c} \quad 3.6$$

or,

$$G = V_o \frac{dp}{dv} \quad 3.7$$

For isotropic elastic soils the shear modulus can be converted to an equivalent Young's modulus E by assuming suitable value of Poisson's ratio ν.

$$E = 2G\ (1+\nu) \quad 3.8$$

In practice following equation is used to obtain E

$$E = 2(1+\nu)Vm \frac{dp}{dv} \quad 3.9$$

Where Vm = mean volume of cavity over elastic phase.

3.3 ELASTIC-PERFECTLY PLASTIC MODEL

The linear elastic model cannot represent the real test behaviour once p_F is reached. Yielding occures at the cavity wall when shear stress reaches the undrained shear strength C_u. This happens when

$$p_F = p_o + C_u \qquad 3.10$$

The volumetric elastic strain needed to reach this stage is given by equation

$$(\Delta V/V)_F = C_u/G \qquad 3.11$$

As the pressure is increased the yielded zone spreads further away from the cavity and soil responce becomes less and less stiff. For such condition Gibson and Anderson (1961) derived the following equation

$$P = P_o + C_u[1 + \ln G/C_u] + C_u\ [\ln \Delta V/V\ ] \qquad 3.12$$

The limiting condition is reached when all soil is deformed plastically and $\Delta V/V = 1$ ($\Delta V/V = \Delta V/(\Delta V+V)$ becomes 1 when $\Delta V \to \infty$).

Hence limit pressuree is given by equation

$$p_L = p_o + C_u\ [1+\ln G/C_u]. \qquad 3.13$$

This equation is extensively used for obtaining C_u in clayey soils. It should be noted that limit pressure is not only the function of shear strength C_u, but also depends on the strain at failure $(\Delta V/V)_F$.

Combining equations 3.12 and 3.13 the general equation which describe the soil responce beyond failure is obtained as

$$p = p_L + C_u \ln (\Delta V/V). \qquad 3.14$$

Thus pressuremeter results when plotted on a log plot should give stright line in the plastic plase of the test. This fact is utilized to obtain the limit pressure by extrapolation (section 3.5.4).

3.4 THEORETICAL CONSIDERATIONS FOR SAND

The behaviour of sand during pressuremeter test is less understood as compared to the corresponding behavior of clay. This is because of two reasons:

(i) All pressuremeter tests performed in sand are drained tests.

(ii) Sands have a tendency to dilate when sheared.

Gibson and Anderson (1961) derived the following relationship for limit pressure in sand.

$$p_L = p_o N^2\phi \qquad 3.15$$

Where,

$$N\phi = \tan^2 (\pi/4 + \phi/2) \qquad 3.16$$

Volume changes due to dilatency are ignored and equation 3.15 gives unrealistically high values of ϕ.

Hughes et al (1977) presented a method which takes into account the effect of volume changes due to drainage and dilatency. But the method is more used with selfboring pressuremeter tests and hence it is not reported here in.

3.5 INTERPRETATION OF THE TEST RESULTS

Once the corrections outlined in Section 2.3.2 are applied to the raw data obtained from a properly conducted pressuremeter test, various soil parameters can be determined using the theories presented in the previous sections. Procedure most commonly adopted for this and the problems usually encountered are discussed in this section.

3.5.1 Estimation of Earth Pressure at Rest (P_o)

The standard method for estimating p_o is to assume that it corresponds to the start of linear region of pressure-volume curve and also to the point of creep curve where creep drops to a low constant value. This methos of estimating p_o from the initial kink in the pressuremeter curve is some times misleading because this initial kink simply represents contact being achieved with the side wall and the position of p_o on subsequent curve depends on how much elastic relaxation has occured initially. There is evidence to suggest that this method underestimates p_o in overconsolidated soils by a considerable amount. Individual values of p_o determined in this way shows a large scatter and in some cases give values lower than the overburden pressures (Marshland and Rensolph, 1977). Although the limit pressure is not much affected by the error in estimation of p_o, the undrained shear strength can be overestimated by as much as 25%.

Marshland and Rendolph (1977) proposed an iterative procedure to estimate p_o from prebored pressuremeter tests. For an ideal test on elastic-plastic soil p: $\Delta V/V$ curve should be linear on the either side of p_o. Thus p_o should lie on the most nearly linear part of the curve, but near the point of inflexion and not at the start of the linear region as assumed in conventional method. From equation 3.10

$$p_F = p_o + C_u$$

Since initial estimation of volume Vo corresponding to the pressure p_o is required to obtain C_u, an iterative procedure is adopted.

A less refined method proposed by Davis and Pell (1980) makes

use of the fact that on pressure-volume curve the point corresponding to p_F is more clearly defined than that corresponding to p_o. Combining equations 3.10 and 3.13 and rearranging the terms the following relationship can be established:

$$C_u = \frac{p_L - p_F}{n(G/C_u)} \qquad 3.17$$

Value of G is determined from early part of the test curve and equation 3.17 is solved by iteration very rapidly. p_o is then obtained using equation 3.10.

A graphical method called 'method of volume origin adjustment'is described by Denby and Hughes (Mair et al.,1957). Curves of p : ln ($\Delta V/V$) are constructed using trial values of the reference volume Vo. The value of p corresponding to the value of Vo which gives the most linear plot of p : ln ($\Delta V/V$) is then taken as best estimate of p_o.

3.5.2 Determination of Modulus

The potential of pressuremeter test lies in its ability to measure mass modulus of the material. However, it should be appreciated that soil has no unique value of modulus and it is more appropriate to call this modulus as 'pressuremeter modulus'. Equations 3.6 or 3.9 can be used to obtain shear or elastic modulus for cohesive or frictional soils. Equation 3.9 can be rewritten as:

$$E = 2(1+\nu)\ \frac{V_o + V_F}{2}\ \frac{(p_F - p_o)}{(V_F - V_o)} \qquad 3.18$$

The fundamental mode of failure during a pressuremeter test is shear mode and value of G obtained is independent of the

drainage condition existing during the test. Value of Poisson's ratio appropriate for the drainage condition of structure should be substituted in equation 3.18 to obtain elastic modulus. This requires some judgement as confirmatory testing is rarely available.

Because of the disturbances that are inevitable during boring of hole, modulus obtained from the initial slope of pressuremeter curve gives a low estimate of in-situ modulus. An unloading reloading cycle performed during the Pseudo-elastic phase of the test gives more realistic values of modulus.

3.5.3 Determination of Undrained Shear Strength (C_u)

Gibson and Anderson (1961) suggested a plot of volumetric strain $\Delta V/V$ on logarithmic axis versus pressure on arithmatic axis for evaluation of C_u, the point corresponding to p_o taken as the origin of strain.

Thus,

$$C_u = \frac{p_2 - p_1}{\ln\left[\dfrac{(\Delta V/V)_2 - p_o/G}{(\Delta V/V)_1 - p_o/G}\right]} \qquad 3.19$$

The method is greatly simplified for soft rocks where ratio p_o/G is typically very small and may be neglected. In this case C_u is simply the slope of $p : \ln(\Delta V/V)$ curve in plastic phase. The method is sensitive to the choice of origin (p_o , V_o).

Alternatively equations 3.13 and 3.17 can be used to obtain C_u. Equation 3.13 can be written as

$$C_u = \frac{p_L - p_o}{N_p} \qquad 3.20$$

Where,

$$N_p = 1 + \ln(G/C_u) \qquad 3.21$$

N_p is analogeus to the N_c in the equation $q = N_c C_u$ and both are related as

$$N_p = 3/4 \ (N_c - 1) \qquad 3.22$$

(Marshland and Rendolph, 1977)

N_p is called 'Pressuremeter Constant'. All methods described above give slightly different values of C_u. Undrained shear strength obtained from pressuremeter test are found to be about 1.2 to 1.5 times higher than C_u obtained from vane shear test or plate load test (Bergado et al., 1986). Reasons for this are not clearly understood but effect of strain rate, partial drainage departure from plane strain and most importantly the disturbances caused during boring process are believed to be responsible.

3.5.4 Extrapolation for Limit Pressure (p_L)

More often than not, the pressuremeter tests are terminated before the limit pressure is reached. Generally the restriction comes not from the pressure capacity of the equipment but from the failure to reach about 41 % of radial strain to obtain the limit pressure defined by $\Delta V/V_o$=1. The simplest way to extrapolate the curve is to extend the curve smoothly till it reaches the point corresponding to double the original size of cavity. The method cannot be used when a test is terminated soon after the initial yield.

Gibson and Anderson (1961) suggested a log-log plot of pressure versus $\Delta V/V$ where V is currentt volume of cavity. The pressure corresponding to $\Delta V/V = 1$ is the theoretical limit pressure required for infinite expansion of the cavity. If V is substituted by reference volume V_o, the conventional limit pressure which corresponds to double the size of cavity is

obtained. Theoretically the difference between two limit pressures for cohesive soil is about 0.69 C_u (Baguelin et al., 1978).

In upside down method a plot of p : 1/V is made. The pressure corresponding to 1/V = 0 gives theoretical limit pressure for $V \rightarrow \infty$.. This method is sensitive to the continued curvature of plot at the last measurements and it generally gives lower values of limit pressure than those given by log-log method (Mair & Wood,1987). However, unlike log-log method, there is no theoretical justification for this method and is not generally recommended.

CHAPTER IV

FIELD PERFORMANCE OF THE EQUIPMENT

4.1 GENERAL

Total six pressuremeter tests had been performed on the campus soil in order to evaluate the performance of newly built equipment and to compare the results with results obtained from Menard type pressuremeter and other field tests. Unfortunately the SUBSOIL DEFORMETER available with the Geotechnical Laboratory was out of order and the results had to be compared with the results of earlier studies undertaken by Singh (1980) and Singh (1982).

4.2 THE SITE

The IIT Kanpur campus is located on the thick alluvial deposites of the river Ganges. The soil is predominantly silt with small amount of clay and fine sand. The ground water table is generally at 3.5 m depth, but large seasonal fluctuations of water table had been observed (Jain, 1977). Because of the negative pore water pressure associated with the fluctuation of water table, top soil is subjected to an effective streess that is higher than the overburden pressure. As a result of this, soil upto a depth of about 6.0 m behaves as a lightly over-consolidated soil with a maximum over consolidation ratio of about 3.0. A 'Kankar' layer of erratic distribution have been observed towards the northern side of the campus at a depth varying from 2 to 4 meter (Jain, 1977; Singh, 1980). Referring to Figure 4.1, earlier

tests were conducted at site B by Singh (1980) and at site C by Singh (1982). Though Singh (1980) reports Kankar layer at about 3 meter depth, because of the changes which took place over a period of 9 years, the Kankar layer was encountered at a shallow depth of 1.0 m. Site B had to be abandoned after the heavy damage to one of the augers caused by Kankar layer. Site A was then selected and standard penetration test, static cone test and pressuremeter tests were performed. Figure 4.2 shows the borehole profile along with moisture content and Atterberg limits of soil at site A. Particle size distribution is shown in Figure 4.3. Water table was not observed upto a depth of 3 meter.

4.3 DETAILS OF TESTS CONDUCTED

The following field tests were conducted:

1. Standard Penetration Test (SPT).
2. Static Cone Penetration Test (SCPT).
3. Strain Controlled Pressuremeter Test.

4.3.1 Standard Penetration Test

The standard penetration test was conducted with a split spoon sampler. The sampler was driven 45.0 cm into the ground by means of a 65 kg. weight hammer falling from a height of 75.0 cm. The number of blows for each 15.0cm penetration was recorded and total number of blows required for last 30.0 cm of penetration was taken as N-value of the layer penetrated. Correction due to over burden was applied using following formula given by Bazara (Kaniraj 1988).

$$N' = N \left(\frac{4}{1 + 4\sigma_o} \right) \tag{4.1}$$

where,

N' - corrected blow count

σ_o - over burden pressure in kg./cm^2 at test depth.

Formula is applicable when $N'/N \leq 2$. Results are given in Table I and plotted against depth in Figure 4.7.

4.3.2 Static Cone Penetration Test

A mechanical type cone having 10 sq.cm area was pushed into the ground by means of a hand operated cone penetrometer of capacity 30 kN. The machine was anchored to the ground by means of four helical plate anchors. The cone was pushed vertically into the ground and load required to do so was measured from pressure gauge reading of a hydraulic jack. Point resistance at any depth could be found only for a length of travel of sleeve (7 cm) after which the total resistance was mobilized as flange engaged the friction mantle with further advancement. Only the cone resistance values were recorded. Results are given in Table I and plotted against depth in Figure 4.7.

4.3.3 Strain Controlled Pressuremeter Test

Pressuremeter test results are very sensitive to the method used for advancing the borehole. Best quality of borehole is obtained with hand augering and the method is highly recommended (Baguelin et.al., 1978). To ensure minimum disturbances a two stage method was adopted in which 60 mm diameter holes made with an open helical auger were enlarged to 68 mm using a post hole auger. Plate 6 shows the equipment ready for testing Tests were conducted in two nearby boreholes in order to check the repeatability of the testing method. The probe was lowered into the position as soon as test depth had been reached and test was

conducted at a strain rate of approximately 1%/min. Volume readings were taken at pressure difference of 10 or 20KPa. Probe was deflated after the test was over and borehole was advanced to the next test depth. Tests were conducted at 0.9 m, 2.0 m and 2.6 m depth in each borehole.During the entire test programme the CAVITEX performed most satisfactorily. There were no problems of leakage, membrane comming out of its grip or beeing punctured by sharp kankars. Corrected pressure-volume curves for BH1 and BH2are shown in Figures 4.4 and 4.5 respectively.

4.4 ANALYSIS OF PRESSUREMETER TEST RESULTS

Following parameters were obtained from pressuremeter test.

(1) Insitu horizontal earth pressure at rest (p_o)

Values of p_o estimated from the initial portion of pressure volume curve are given in Table I and plotted against the depth in Figure 4.6 a. Values of coefficient of earth pressure at reest (K_o) computed by taking bulk density of 18.5 kN/m^3 are given in Table II. K_o values estimated from the curves given by Booker and Ireland (Lambe and Whitman, 1969) taking over consolidation ratio of 3 and plasticity index 15 comes to be about 0.8.

(2) Yield Pressure (p_F):

Pressure values corresponding to the end of linear portion in pressure-volume curve are given in Table I.

(3) Limit Pressure (p_L):

Pressurmeter curves were extrapolated from about 47% volumetric strain to 100 % strain using log-log method to obtain limit pressure corresponding to doubling the size of cavity. The results are plotted in Figure 4.8 and 4.9. Limit pressure values

are given in Table I and plotted against depth in figure 4.6.

(4) Elastic Modulus (E):

Values of E were calculated using equation 3.18 by assuming Poissons ratio of 0.33. The results are given in Table I and plotted against depth in Figure 4.6 c.

(5) Undrained Shear Strength (C_u):

C_u values calculated from equation 3.13 are given in Table I and plotted against depth in Figure 4.7 a. Pressuremeter constant N_p for campus soil ranges between 3.9 to 4.6.

Standard penetration test, cone penetration test and pressuremeter test results from previous studies by Singh (1980) and Singh (1982) are reproduced in Table II.

4.5 DISCUSSION AND COMPARISONS

Following facts emerge from the study of the results obtained in this limited test program.

1. The shape of almost all pressure-volume curves is following the general trend of a typical pressuremeter curve shown in Figure 1.2. The curves are more close to the ideal curve for top stiff soil layer. Referring to Figure 4.8 and 4.9 the end portions of ln p : ln ($\Delta V/V$) curves are fairly straight as predicted by the theory.

2. There is a general trend in strength profiles obtained from all three field tests. Strength which is high at shallow depth because of the low moisture content, drops sharply at 2.0 meter and increases again as a result of the increase in confining pressure and presence of kankars, at 2.6 meter.

3. Good repeatability of CAVITEX results is evident from the

study of Figures 4.6, 4.7 and 4.10. Not only the calculated values of parameters but also the shapes of pressuremeter curves are closely matching for two boreholes. However,results are less consistent for 2.6 m depth probably because of the presence of observed kankar layer. Singh (1980) also arrived at asimilar conclusion. Since very few tests has been performed, it is difficult to make any statement regarding statistical aspect of repeatability and reproducibility of the test.

4. It is always illuminating to study relationships between various parameters obtained from same test or different tests. This has been done in figure 4.11 to 4.13. A good trend can be observed in figures 4.11 a, 4.12 a, 4.12 b and 4.13 a. However, no attempt has been made to establish any correlation because of insufficient data.

In order to study the differences, if any,between parameters obtained using newly built pressuremeter and Me'nard type pressuremeter(SUBSOIL DEFORMETER), a comparison has been made with the results of previous studies by Singh (1980) and Singh (1982). However, there is little point in comparing the absolute values obtained from three test programs conducted at differnt sites, during different time of year and separated in time span of 9 years. Therefore ratios of different parameters have been taken and compared. The assumption made here is that these ratios are characteristics of soil type and testing method, however, this may not be necessarily true. Table III and Table IV show the ratios of differnt parameters for present study and previous studies respectively. Following facts can be observed.

(1) CAVITEX, for the testing method followed, gives higher values

of E/p_L and E/q_C. This implies that higher values of E are obtained with new equipment. This is a good sign since pressuremeter test is well known for underestimating the modulus.

(2) Higher values of E/p_L and q_C/p_L indicates that test under estimates limit pressure.

(3) As a direct consequence of (1) and (2), higher ratios of p_L/C_u and q_c/C_u are obtained. This indicates that C_u is underestimated as comnpared to the conventional pressuremeter test. This is also a positive sign as pressuremeter test is notorious for overestimating undrained shear strength (Burzado, 1986, Nasr et al., 1988).

(4) Higher values of p_L/p_F indicates that failure is initiated at lower volumetric strains, which infact has been observed on pressure-volume curves obtained from equipments of two types.

However, a properly designed, detailed study should be made to verify the above conclusions.

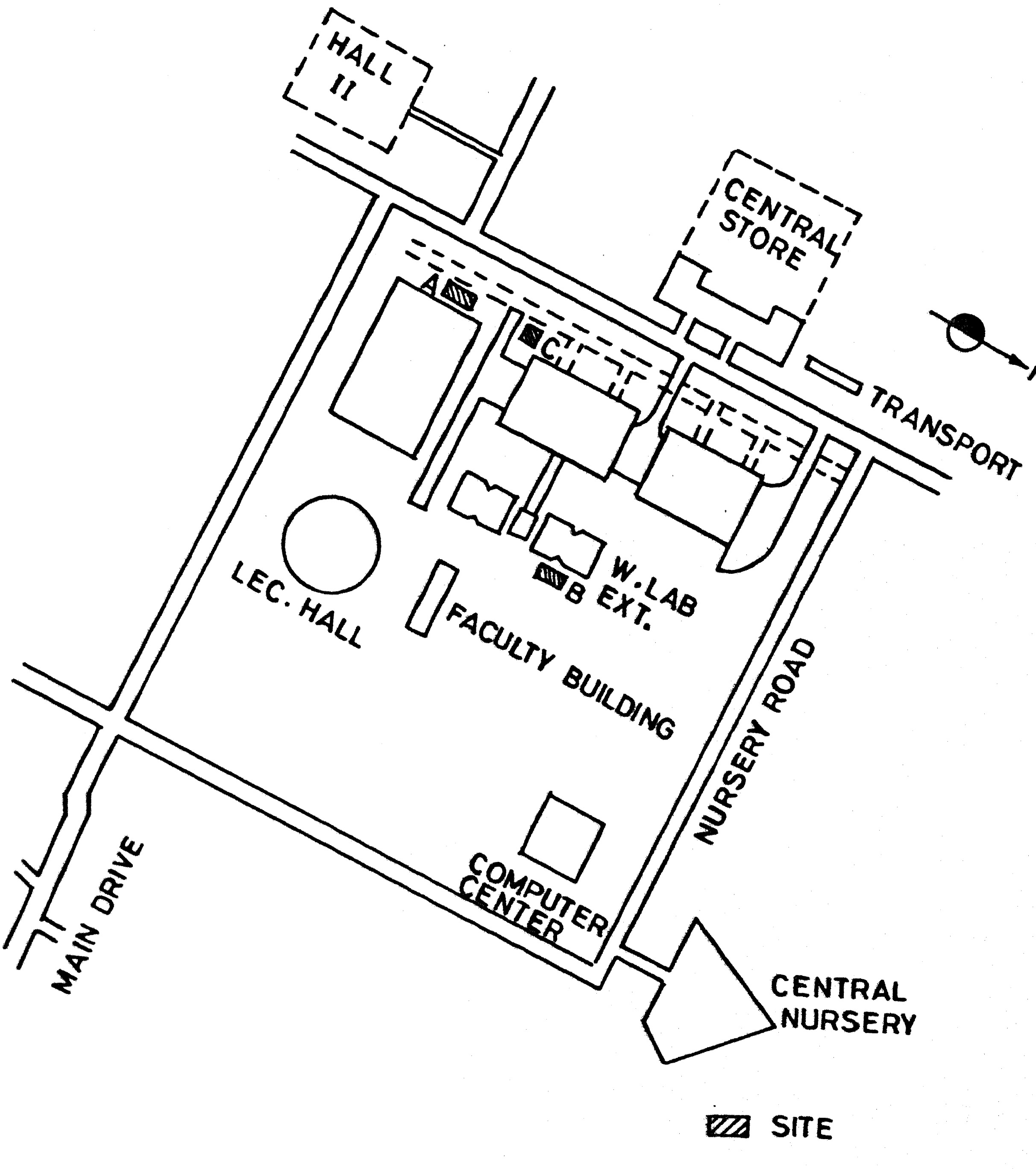


FIG. 4-1 LOCATION OF TEST SITE IN CAMPUS.

Depth (GL)	Description of structure	Soil classification	Clay ≤.002mm %	Silt .002-.075 mm %	Sand .075-4.75 mm %	W_n	W_L	W_p
GL–0.9	Clayey silt with fine sand	CL	20	68	12	16.0	31.4	18.5
0.9–2.0	Clayey silt with fine sand	CL	12	69	19	19.6	29.1	20.4
2.0–2.6	Clayey silt with fine sand and kankar	CI	8	71	21	21.8	34.0	21.1

FIG. 4.2 BORE HOLE PROFILE

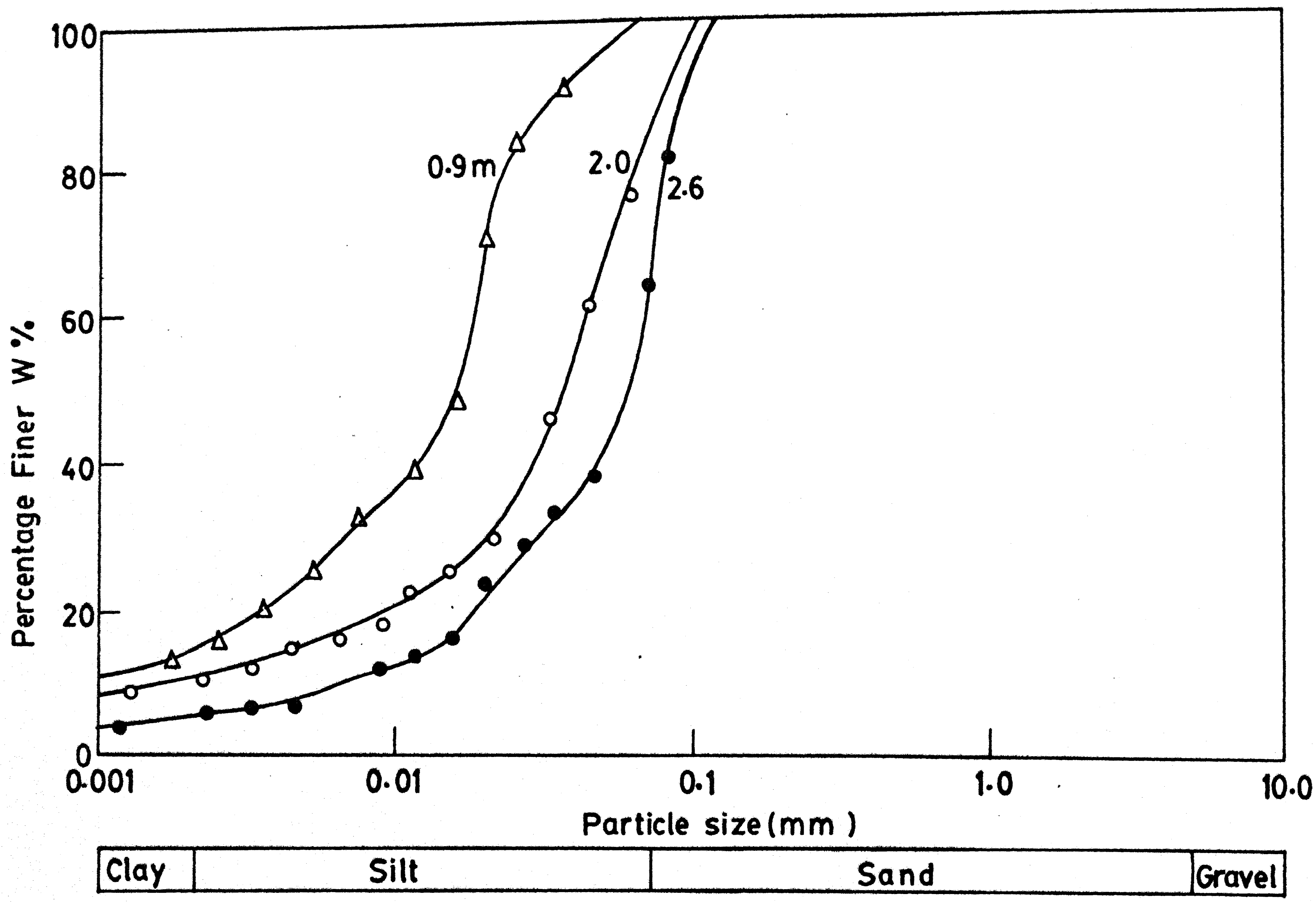


FIG. 4.3 PARTICLE SIZE DISTRIBUTION CURVE

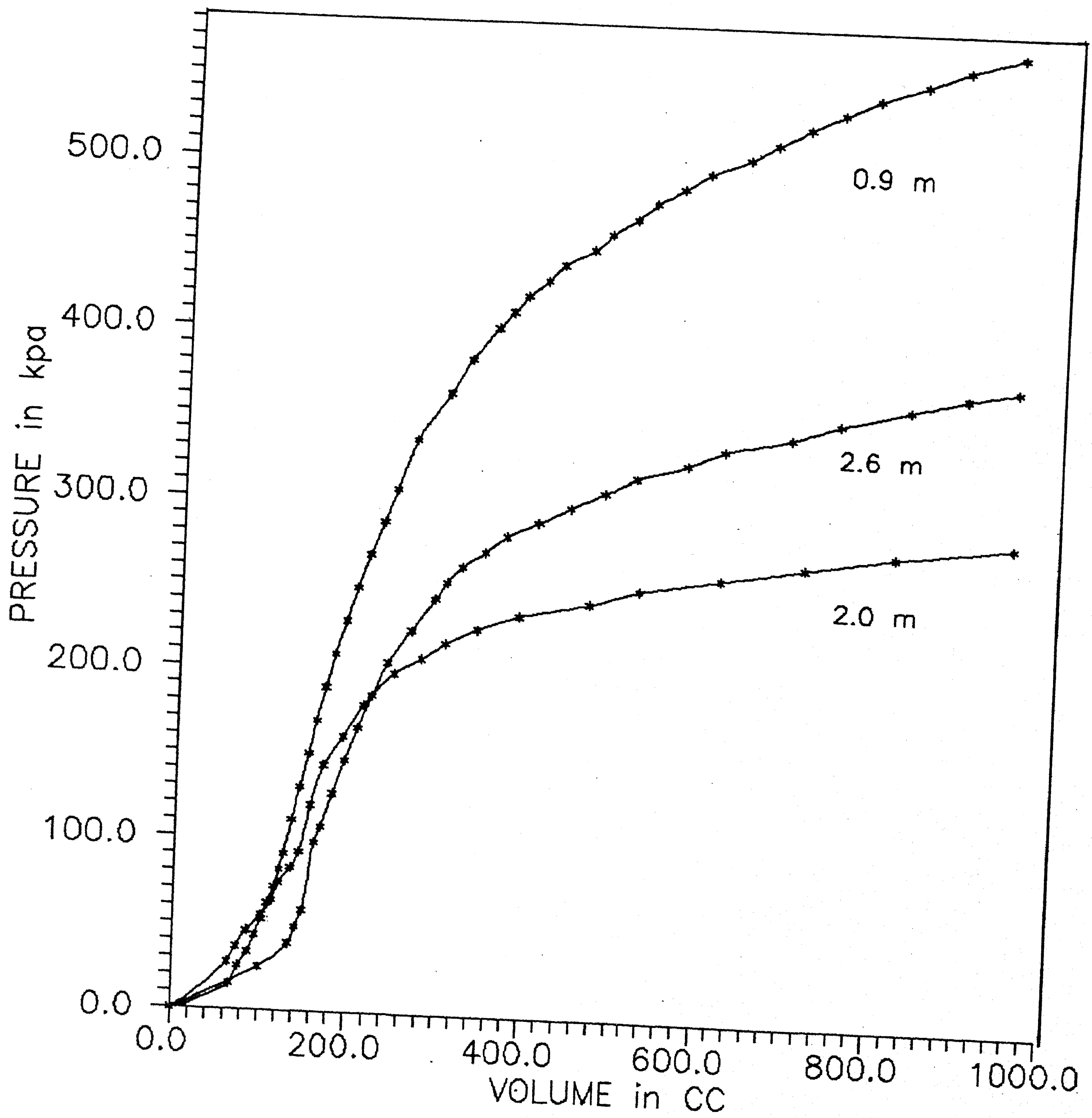


FIG. 4.4 PRESSUREMETER CURVES FOR BOREHOLE 1

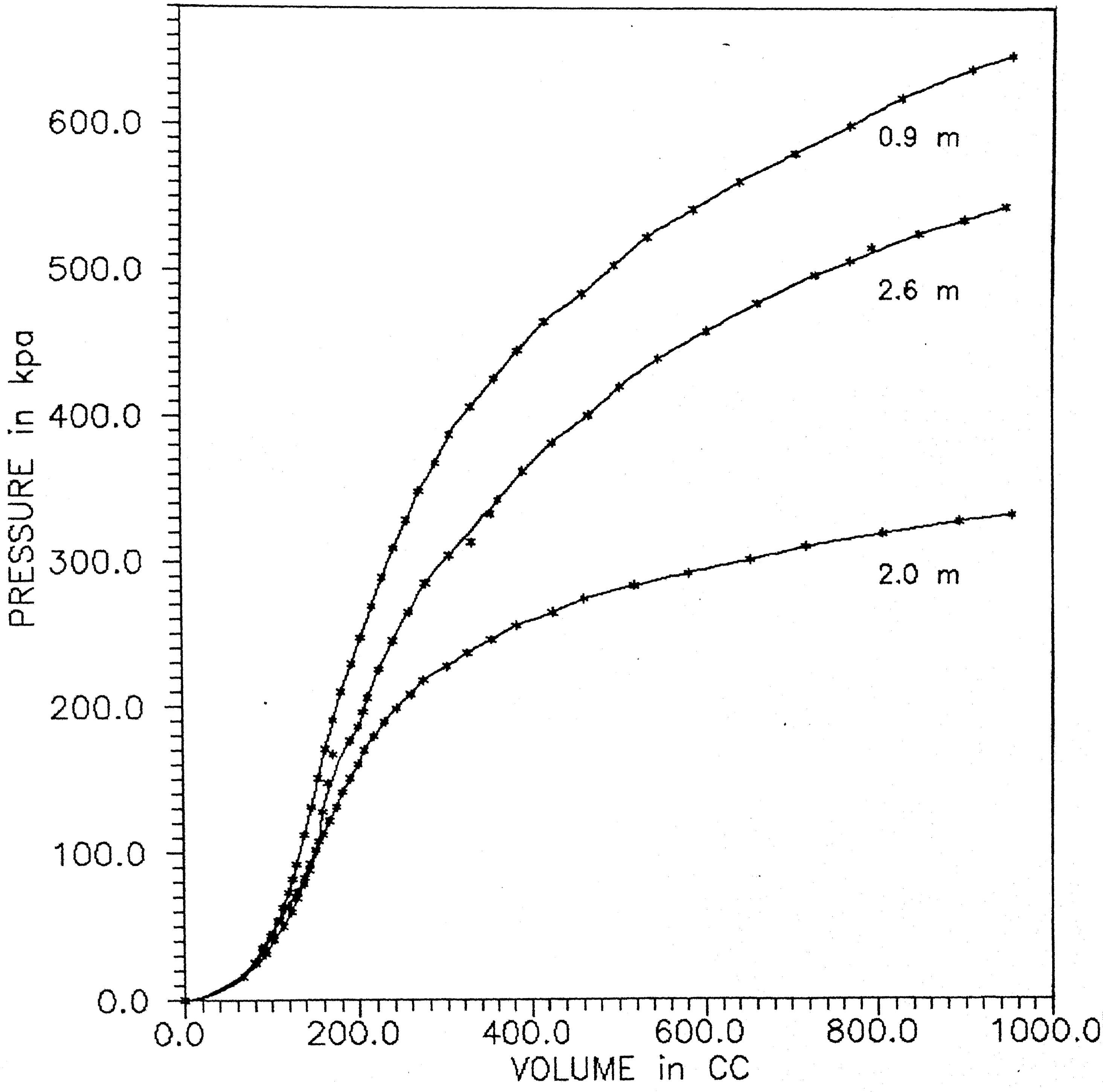


FIG. 4.5 PRESSUREMETER CURVES FOR BOREHOLE 2

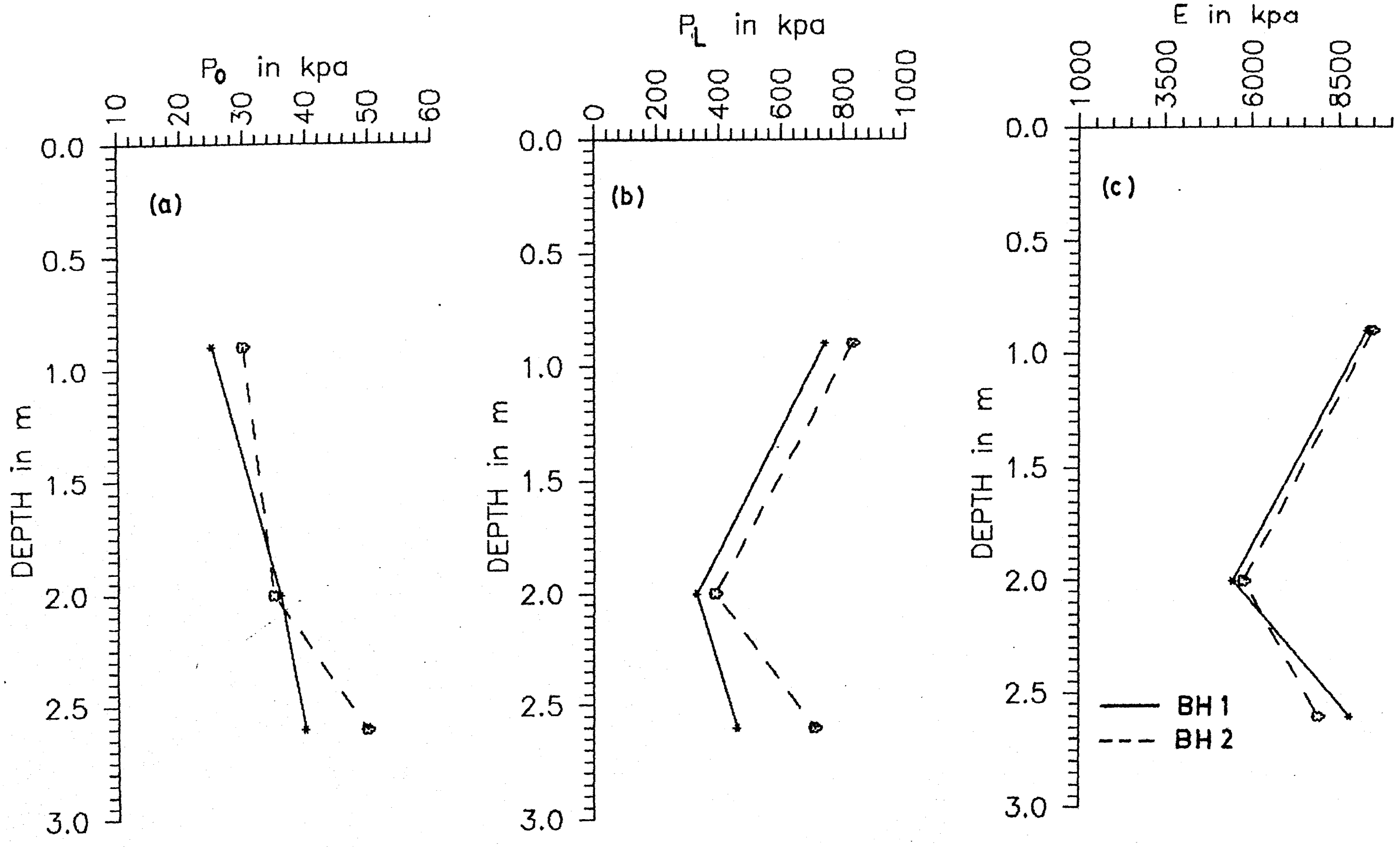


FIG. 4.6 VARIATION OF P_0, P_L AND E WITH DEPTH

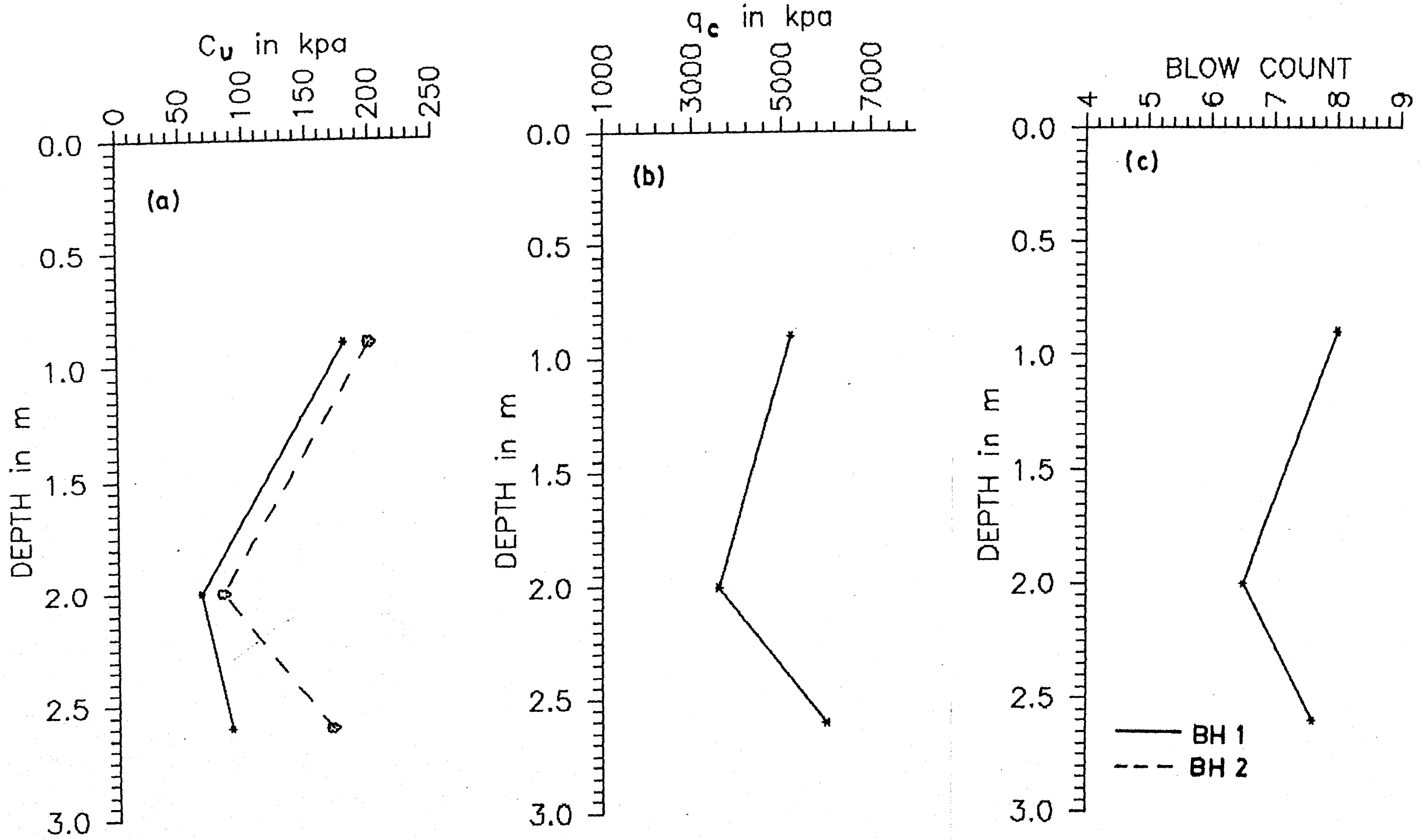


FIG. 4·7 VARIATION OF Cu , q_c AND N WITH DEPTH

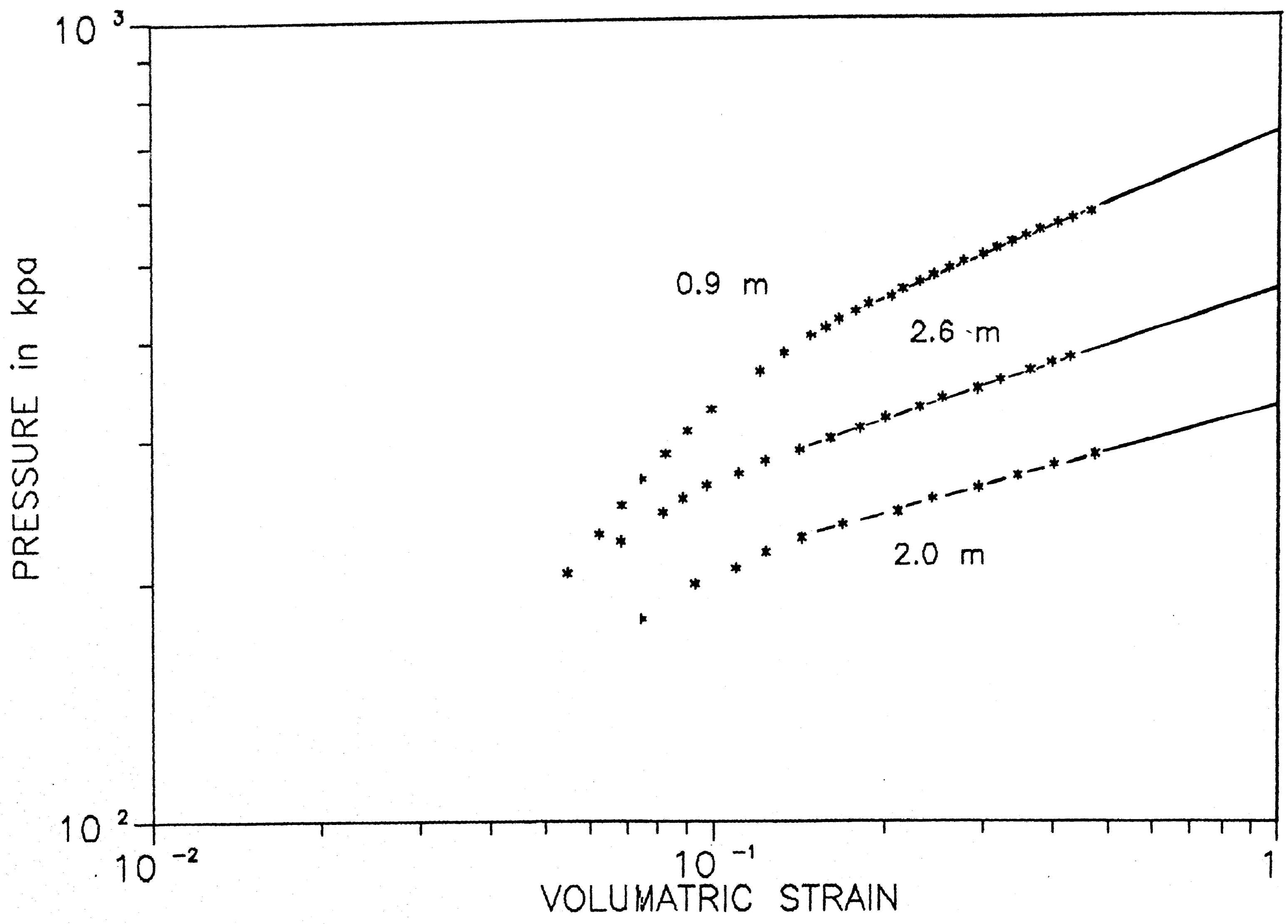


FIG. 4.8 EXTRAPOLATION OF P_L FOR BOREHOLE 1

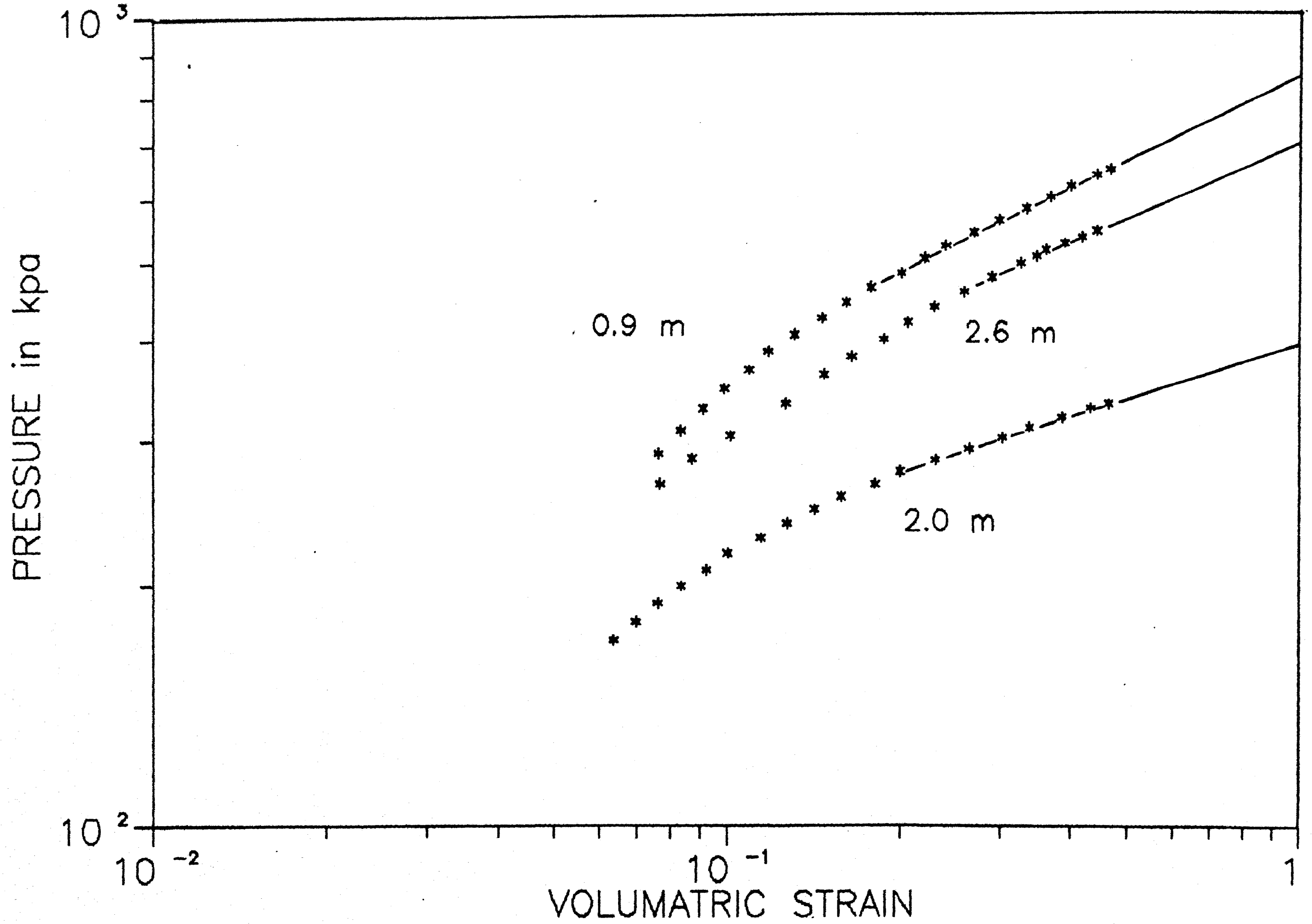


FIG. 4.9 EXTRAPOLATION OF P_L FOR BOREHOLE 2

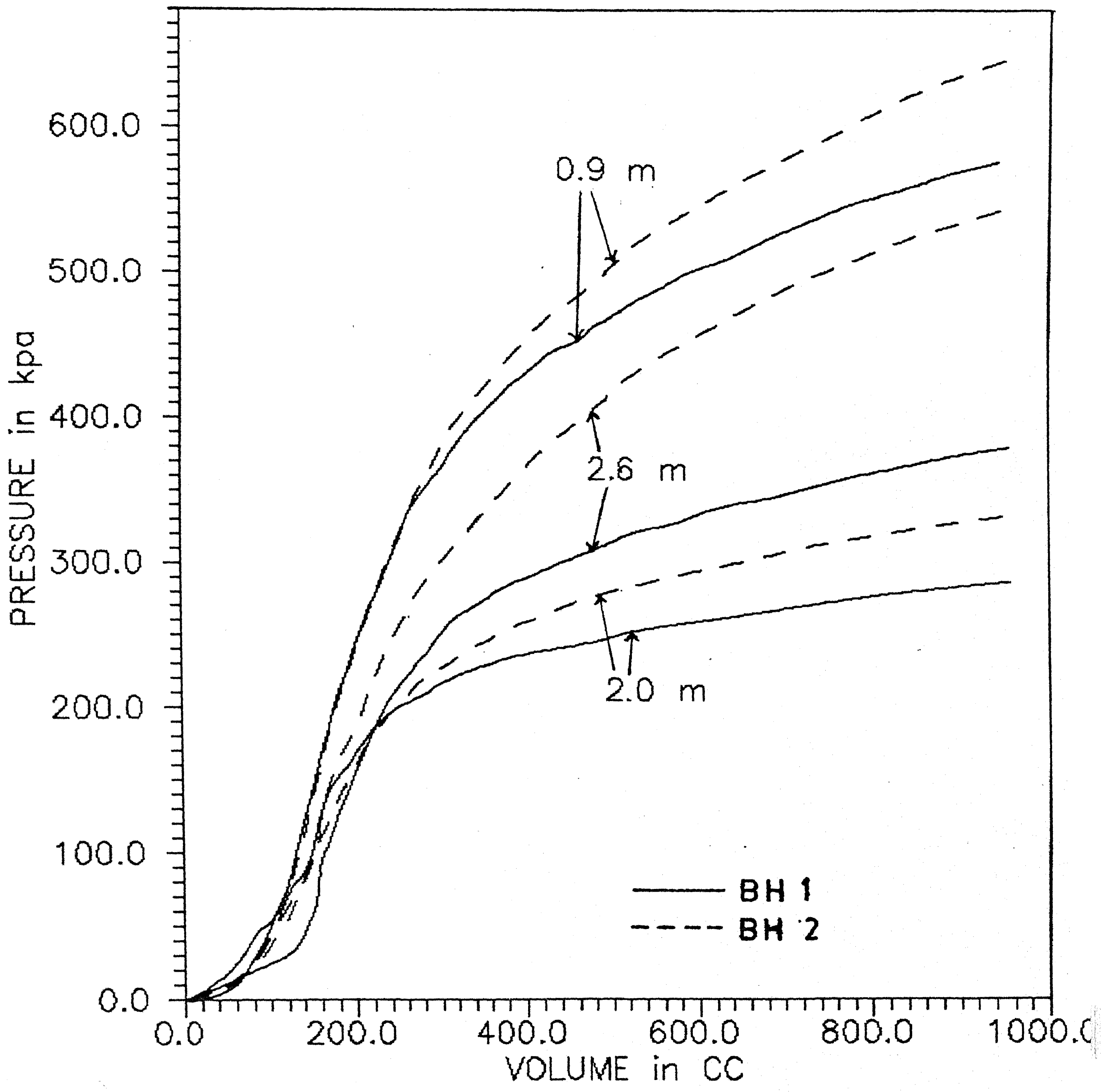


FIG. 4.10 COMPARISON OF PRESSUREMETER CURVES FROM TWO BOREHOLES

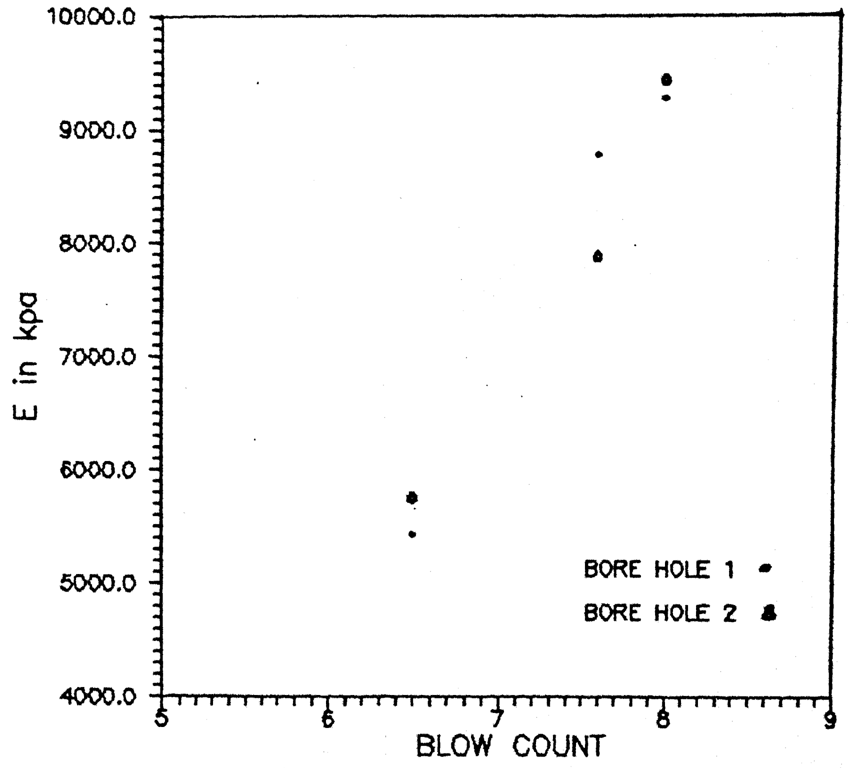


FIG. 4-11 (a) RELATIONSHIP BETWEEN E AND N

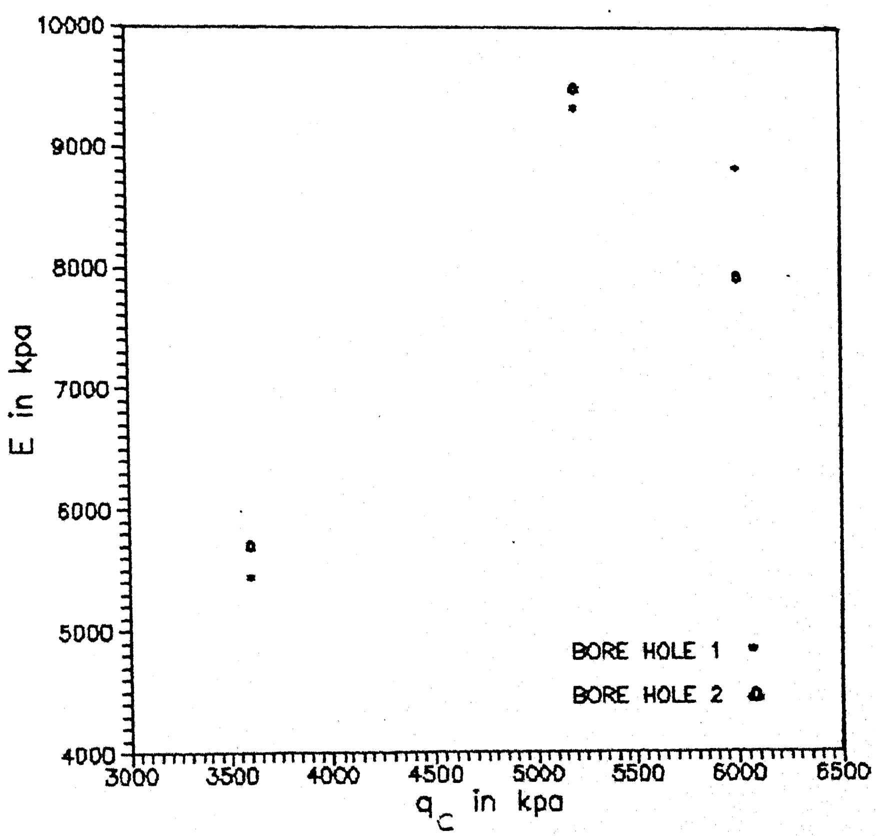


FIG. 4-11 (b) RELATIONSHIP BETWEEN E AND q_c

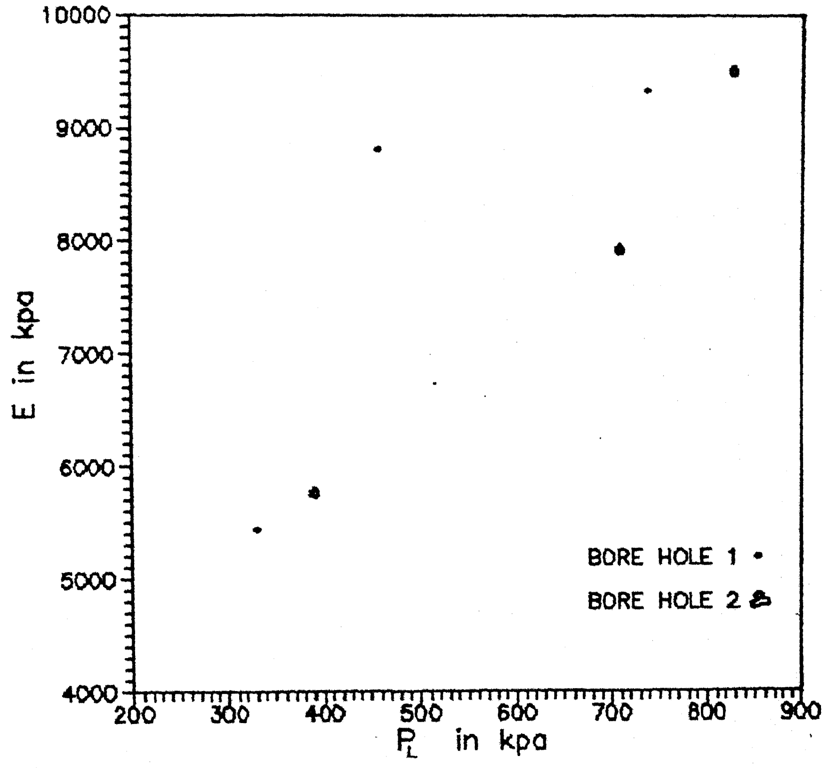


FIG. 4·12 (a) RELATIONSHIP BETWEEN E AND P_L

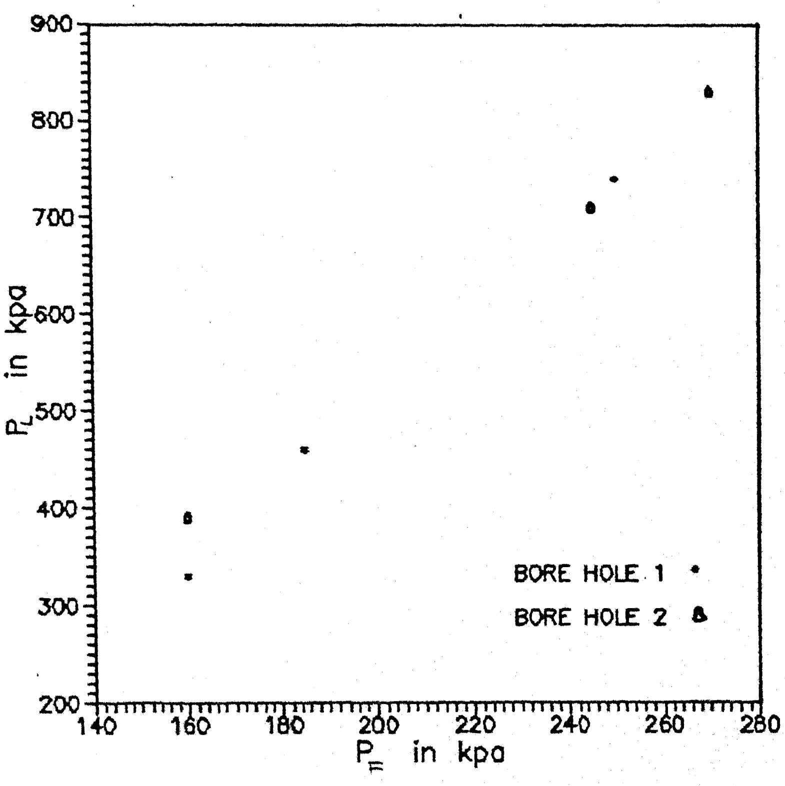


FIG. 4·12 (b) RELATIONSHIP BETWEEN P_L AND P_F

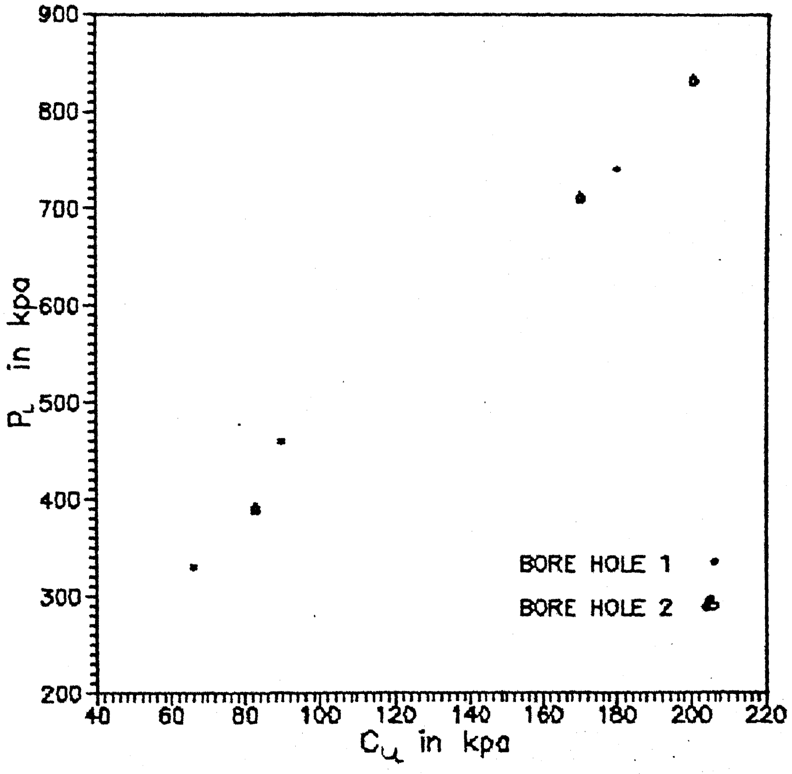


FIG. 4·13 (a) RELATIONSHIP BETWEEN P_L AND Cu

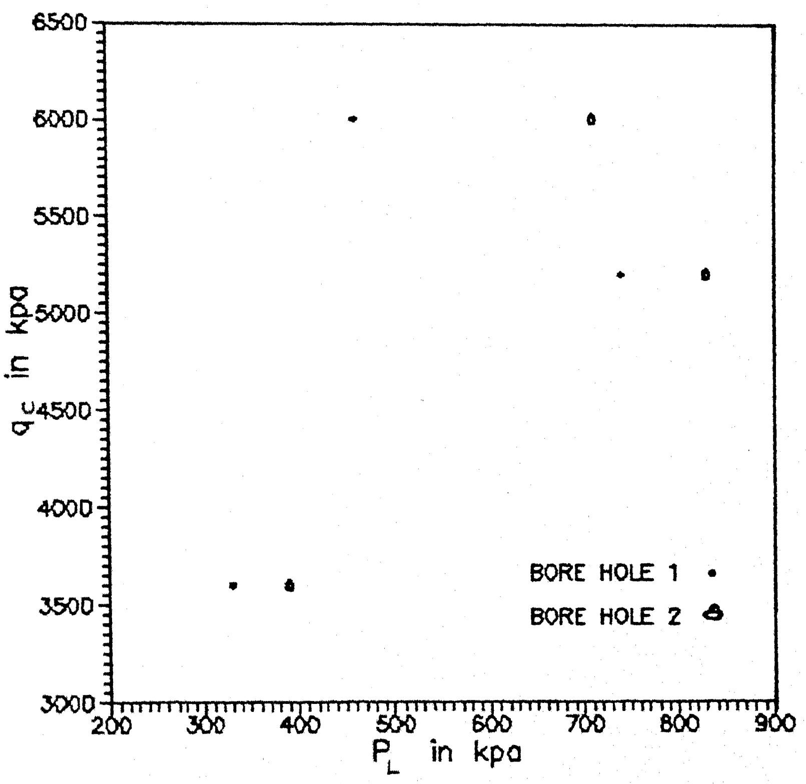


FIG. 4·13 (b) RELATIONSHIP BETWEEN q_c AND P_L

Plate 6

DEPTH m	P_o KPa		P_F KPa		P_L KPa		E KPa		C_u KPa		q_c KPa	N
	BH1	BH2	BH1	BH2	BH1	BH2	BH1	BH2	BH1	BH2		
0.9	25	30	270	250	740	830	9300	9460	180	200	5200	8
2.0	36	35	160	160	330	390	5440	5760	66	83	3600	6
2.6	40	50	245	185	460	710	8800	7900	90	170	6000	7

TABLE I - TEST RESULTS FROM PRESENT STUDY

DEPTH m	P_o KPa		P_f KPa		P_L KPa		E KPa		C_u KPa **		q_c KPa		N	
	YS	VKS	YS	VKS	YS	VKS	YS	VKS	YS	VKS	YS	VKS	YS	VKS
1.0	15.5	14.2	-	247	517	342	4040	1700	152	123	3400	2050	10	-
2.0	28.0	132	-	225	483	378	4100	3900	131	97	2500	2500	8	-
3.0	56.0	167	-	357	765	637	7900	5128	188	169	4500	2950	16	-

** RECALCULATED USING ORIGNAL VALUE OF E

YS - SINGH (1980)
VKS - SINGH (1982)

TABLE - II TEST RESULTS FROM PREVIOUS STUDIES

DEPTH m	E/P_L		P_L/P_F		P_L/C_u		E/q_c		E/N		q_c/P_L		P_o/σ_z	
	BH1	BH2	BH1	BH2	BH1	BH2	BH1	BH2	BH1	BH2	BH1	BH2	BH1	BH2
0.9	12.5	11.4	2.96	3.07	4.1	4.1	1.79	1.81	11.6	11.8	7.0	6.3	1.5	1.8
2.0	16.5	14.8	2.0	2.43	5.0	4.7	1.51	1.60	8.37	8.8	10.9	9.2	0.97	0.95
2.6	19.1	11.1	2.51	2.89	5.4	4.2	1.47	1.31	11.6	10.4	13.0	8.5	0.83	1.04
AVERAGE	14.23		2.64		4.6		1.58		10.4		9.1		1.18	

TABLE - III RATIOS OF PARAMETERS FROM PRESENT STUDY

DEPTH m	E/P_L		P_L/P_F		P_L/C_u		E/q_c		E/N		q_c/P_L		P_o/σ_z	
	YS	VKS	YS	VKS	YS	VKS	YS	VKS	YS	VKS	YS	VKS	YS	VKS
1.0	7.81	5.11	-	1.39	3.4	2.78	1.2	0.85	4.04	-	6.57	6.0	0.86	7.9
2.0	8.5	10.33	-	1.68	3.7	4.06	1.64	1.56	5.12	-	5.17	6.62	1.28	3.67
3.0	10.3	8.04	-	1.78	4.0	3.77	1.75	1.74	4.93	-	5.88	4.63	0.96	3.09
AVERAGE	8.9	7.83	-	1.61	3.7	3.54	1.53	1.38	4.7	-	5.87	5.74	1.03	4.88

YS - SINGH (1980)
VKS - SINGH (1982)

TABLE - IV RATIOS OF PARAMETERS FROM PREVIOUS STUDIES

CHAPTER V

CONCLUSIONS AND SCOPE OF FUTURE WORK

5.1 CONCLUSIONS

Following conclusions are drawn on the basis of the present work.

1. The newly developed equipment (CAVITEX) is definitely an improvement over the conventional type of pressuremeter due to the following reasons.

   (a) It is compact, light weight and hence transportable to remote sites.

   (b) It does not require gas cylinder to develope pressure which eliminates the recurring costs.

   (c) The equipment is extremely simple to operate and designed in such a way that little modification can make it automatic.

   (d) Calibration is straight forward and done within short time.

   (e) The cost is very low (about 10% of the cost of available models).

2. During the entire test program performance of the equipment was entirely satisfactory. No leakage was observed in the hydraulic circuit. There was no problem of membrane being punctured by sharp objects eventhough the equipment had been tested in moderately hostile ground condition.

3. The results obtained from the present study are having the

same order of magnitude as those reported in the previous studies using SUBSOIL DEFORMETER. However, ratios of certain parameters differ and further study is necessary.

4. Small variation in soil strength are reflected in the results obtained with CAVITEX. The trend in the variation of E and p_L with depth is comparable with the trend in SPT and SCPT results Good repeatability in the test results has been observed.

5.2 SCOPE OF FUTURE WORK

(A) Following studies are required to acquire the confidence which will be sufficient to put the equipment in field use.

(1) A detaileld comparison of stress-strain response (pressure-volume curve) as obtained by the CAVITEX with that obtained by conventional pressuremeter test in relatively homogeneous soil.

(2) An elaborated program to establish correlations with others field and laboratory tests.

(3) Study of pressure distribution around the probe during testing and more refined calibration to allow for volume and pressure losses.

(4) Study of expanded shape of the probe within soil.

(B) Following modifications are possible with the current equipment.

(1) Introduction of electricprime mover with a gear system to advance the piston at different rates.

(2) Addition of vacuume gauge to measure pressure-volume response before the positive pressure is built up in the circuit.

(3) Introduction of data acquisition system to collect, store and process the test results.

(4) Introduction of selfboring module to facilitate the installation of probe within the ground with minimum disturbances.

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